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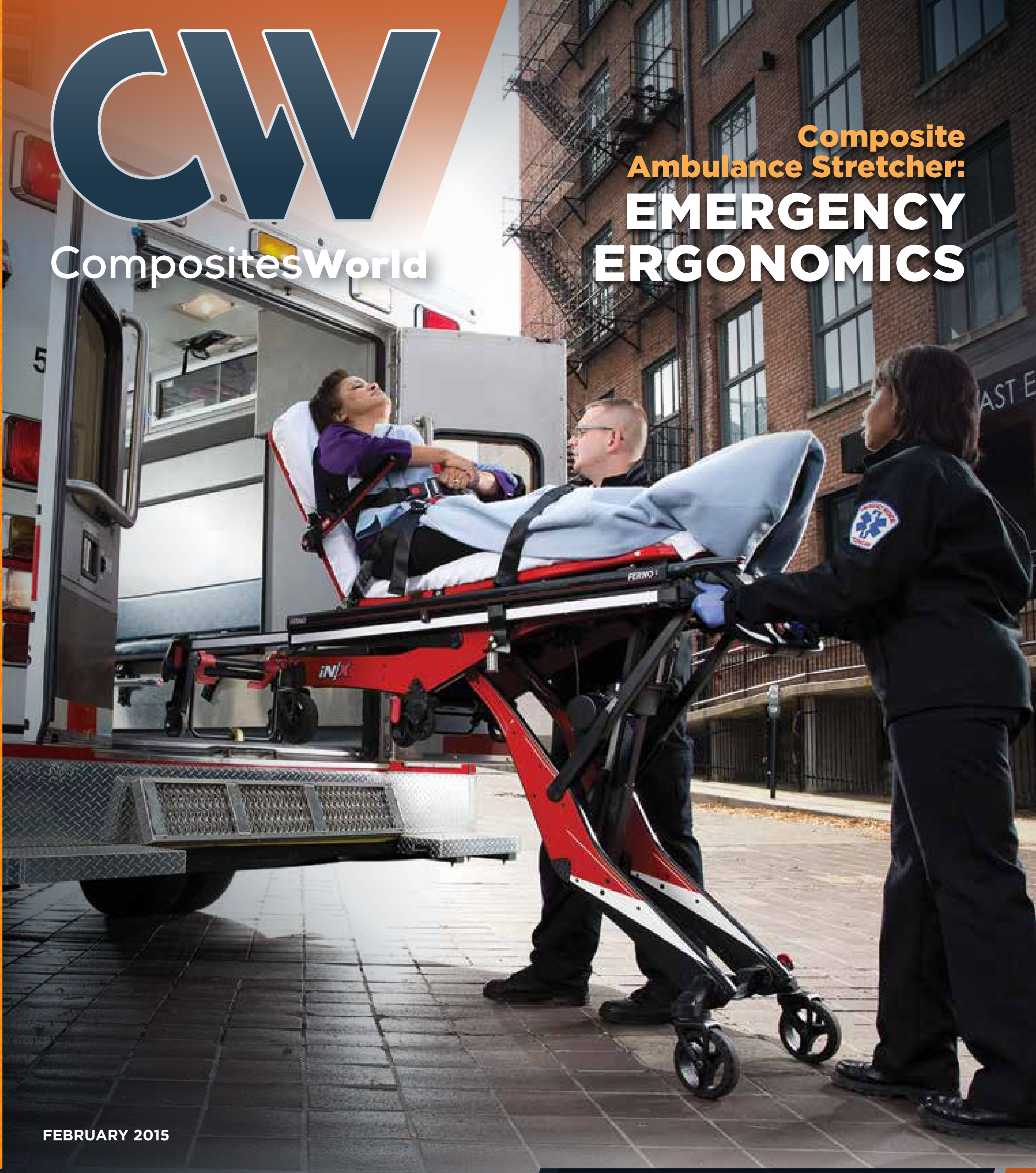

Composite Ambulance Stretcher: EMERGENCY ERGONOMICS

FEBRUARY 2015

NASA: Hybrid Steel/Composite Gears for Rotorcraft? / 20

Plant Tour: Exelis Aerostructures, Salt Lake City / 28

NONA Composites' CFRP REACH Camera Boom / 34

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VOL 1 № 2

FEBRUARY 2015 / Vol: 1 Nº: 2

COLUMNS

4 CW From the Editor

6 CW Past, Present & Future

8 CW Perspectives & Provocations

10 CW Design & Testing

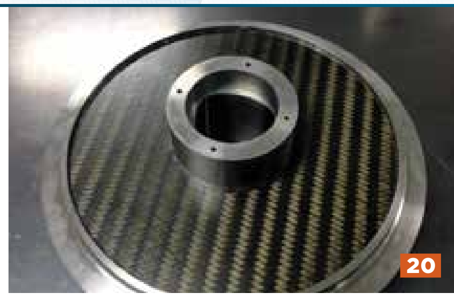
12 CW Business Index

20 CW Work In Progress I — New Aerospace Niche: Helicopter Transmission Gears?

CW technical editor Sara Black reports on a NASA study that shows steel/composite hybrid gears save significant weight, and could mitigate vibration-related noise.

24 CW Work In Progress II — Thermoplastic Composite Pressure Vessels for FCVs

CW contributing writer Peggy Malnati says that two UK consortiums are addressing the durability, weight and cost challenges of high-pressure tanks for hydrogen fuel-cell powered vehicles.



20

24

28

34

FEATURES

28 Plant Tour: Exelis Aerostructures, Salt Lake City, Utah

Established in the 1960s, this longtime aerospace composites manufacturer specializes in braid-reinforced composite shafts and struts for aircraft, but neither hidebound nor immobile, there's much more to this Utah, US-based rising star.

By Jeff Sloan

34 Inside Manufacturing: CFRP Camera Boom Enables Safe Spill Inspection

NONA Composites' 32m REACH structure meets a tight remediation schedule for a radioactive materials spill at the US Department of Energy's Waste Isolation Pilot Plant near Carlsbad, NM, US.

By Ginger Gardiner

» DEPARTMENTS

13 CW Trends
41 CW Calendar
42 CW Applications
43 CW New Products
44 CW Marketplace
45 CW Ad Index
45 CW Showcase

» ON THE COVER

Emergency medical services equipment supplier Ferno (Wilmington, OH, US) has launched the iN∫X ambulance stretcher, known by emergency medical technicians (EMTs) as a cot. iN∫X is the world's first motorized EMS cot to feature two pairs of independently operated legs. Made of composites, each leg supports twice the cot's total rated weight.

Source / Ferno

FOCUS ON DESIGN

46 Managing Weight in Emergency Medical Transport

Repetitive strain risk for first responders sends this emergency equipment provider back to the drawing board to develop a more ergonomic cot.

By Jeff Sloan

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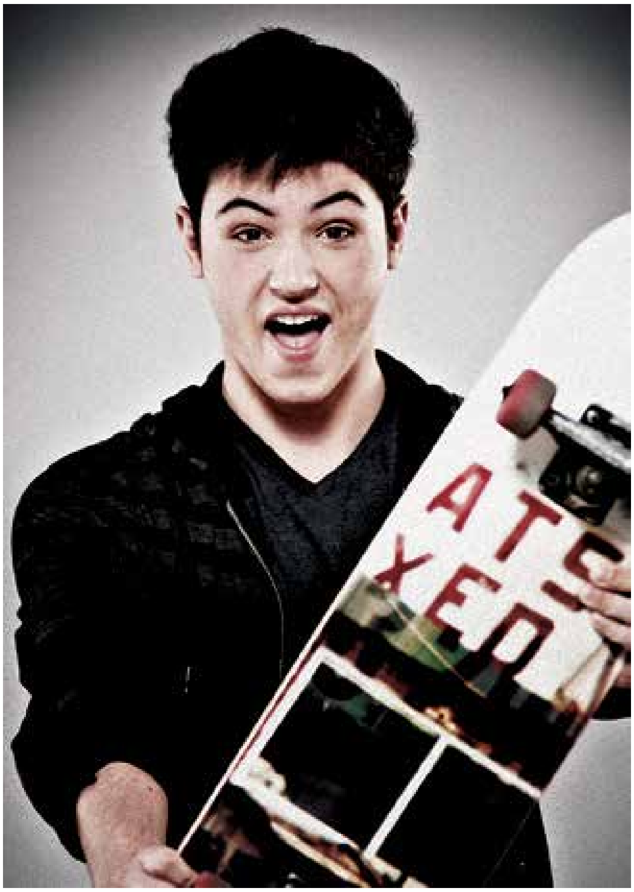

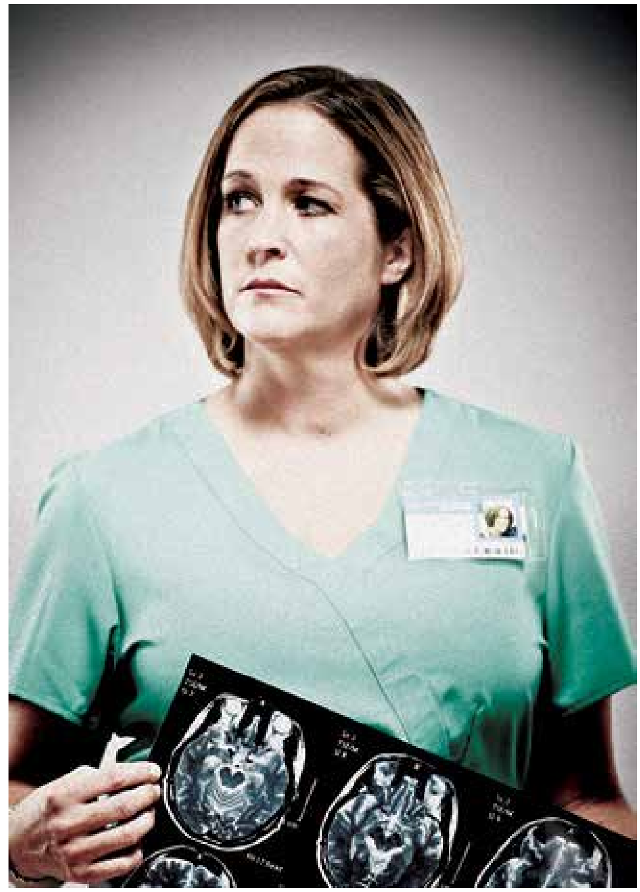

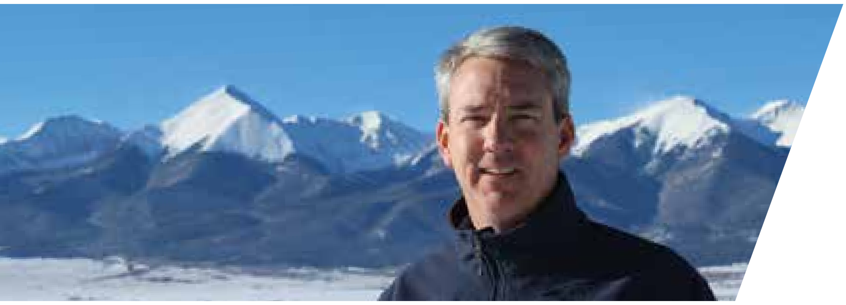

The biggest composites news of 2015, thus far, was the Jan. 9 announcement that the University of Tennessee's Institute for Advanced Composites Manufacturing Innovation (IACMI) had received a highly coveted and much anticipated US$70 million investment from the US Department of Energy (DoE) for composites R&D. The DoE funds will be combined with US$189 million committed to IACMI by the Institute's partners for a grand total of US$259 million. That's a *lot* of dollars.

Can IACMI propel us out of adolescence into adulthood?

The big question now is, *What will come of this investment?*

Stated goals are ambitious: Reduce overall manufacturing costs by 50%, reduce the energy used to make composites by 75% and increase the recyclability to more than 95% within the next decade. One would think that US$259 million could take us a long ways toward meeting these goals.

There are, however, a lot of cooks in the IACMI kitchen. The organization will be led by a group of seven core partners: the University of Tennessee, Michigan State University, Purdue University, the University of Kentucky, the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL) and the University of Dayton Research Institute (UDRI). Following their lead is a long and diverse list of other partners that includes other universities, institutes, economic development centers and many industry suppliers.

At the top of the IACMI organizational chart is CEO Craig Blue, who will collect the money and manage the partnership's *122* participants. To give this sprawling enterprise a little structure, he has organized it into five geographic regions, each with a unique focus: Michigan, vehicles; Colorado, wind turbines; Ohio, compressed gas storage; Indiana, design, modeling and simulation; Tennessee/Kentucky, materials and processing technology.

No matter how you slice it, IACMI has its work cut out for it. Composites, as you know, have a lot going for them: High strength and stiffness, light weight, durability, corrosion resistance, parts consolidation. Composites also have a lot going against them, all of which fall under the heading of "different" — different than steel, aluminum and other legacy materials, which are amorphous and isotropic, and for which material data is plentiful, design/simulation software is mature, and processing methods are established. Composites are none of the above. They are processed by widely varied and still comparatively slow means. Data are lacking. Simulation is in its gawky teenage stage, and the polymorphous nature of composites vastly compounds the difficulty of process control, product consistency and manufacturing repeatability.

To those who work with isotropic materials, composites offer a whole new world of potential benefits. But even an experienced designer or manufacturing engineer who is new to composites has few easy-to-use technical resources available to help him or her move comfortably into the world of composites fabrication.

Up to now, this hasn't stopped progress. Our industry has happily relied on composites' inherently superior mechanical properties and unique tailorability to overcome the design and manufacturing challenges. But OEMs are signaling that their patience is waning — these hurdles must be lowered if composites are to keep their place at the manufacturing table. We're hearing this from the aerospace and automotive markets in particular, whose aluminum and steel suppliers have been busy developing new products that offer greater strength- and stiffness-to-weight than before, process in familiar fashion and come at a more economical price point.

Can IACMI propel us out of adolescence into adulthood? Its size and the scope of the partnership seem to make it a good candidate. In any case, evolution is now a necessity, and *someone* must lead the way. John Byrne, Boeing's VP of aircraft materials and structures, put it this way at *CW's* Carbon Fiber 2014 conference in December: "The composites industry needs to grow up, and fast."

JEFF SLOAN — Editor-In-Chief

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Discrepancies: Reducing them to increase profit

This is your worst nightmare . . . .
You have pulled out all the stops to complete a major composite assembly. Your customer has told you that there is serious impact if you fail to meet the delivery schedule. Your quality rating might hang in the balance. Then you get the phone call: This all-important assembly had just been issued a Discrepancy Report (DR) by the quality department. You rush to the shop floor to view the problem first hand and experience that sinking feeling in your stomach. This is not a minor anomaly that can be used "as is." It's a showstopper. You make a phone call to cancel whatever plans you had for the evening, and you dig in for the long night ahead. *If only there were a way to have avoided this problem*, you think. But then you remind yourself that unforeseen problems are part of the job in the composites industry.

But are they? Must we simply live with DRs? In October 2014, *CompositesWorld*'s Web site published a *CW Blog* titled "Turning data into gold" (short.compositesworld.com/DataGold) in which there were examples of how collecting and interpreting Big Data can help avoid the writing of DRs. What was not covered is the actual impact of a DR on profitability. My company has interviewed a number of composites manufacturers and uncovered information about the true extent of the costs involved in writing a DR. It is our belief that every composites manufacturer needs to ask and answer a critical question: *What is the actual cost of failure?*

It is our belief that every composites manufacturer needs to ask, *What is the actual cost of failure?*

Every discrepant part requires a significant investment, whether the part is shipped or scrapped. However, it is easy to overlook the *total cost* associated with bad parts. The initial investment begins with the cost of producing the part. This includes the cost of planning, toolmaking, materials and process consumables, labor, machine time and overhead built into that part. Once a part is declared nonconforming, a DR must be issued, compounding those costs.

The initial cost is associated with DR paperwork, which varies depending on the size, complexity and overhead structure of each organization. For second- and third-tier suppliers the cost of initiating a DR may be relatively low (US$500-US$1,000 or €385-€770). Estimates by Tier I suppliers and OEMs, however, can range as high as $4,000 (€3,080) per DR. One Tier II supplier recently estimated that as much as 4-5% of the company's gross revenues were consumed by initiating DRs to cover discrepant hardware. *This only includes writing the DR, not the cost of its disposition.*

The expense of initiating a DR has a significant negative impact on profit but, in fact, it's just the tip of the iceberg. When DR paperwork is complete, the company confronts a complex decision tree. If the discrepancy doesn't affect form, fit or function it might be dispositioned to "use as-is" and be reinserted into the manufacturing flow. If not, there are two options: A less expensive part might be scrapped and a replacement built from scratch, retracing the entire manufacturing process. For more expensive parts, it might be more cost-effective to pursue a repair option. But this typically triggers a Material Review Board (MRB) action, likely to include most if not all of the following:

- Formation of an investigative team
- Involvement of the customer
- Collection of information
- Research
- Conduct of a design of experiment
- Design and analysis of a corrective action
- Investigation of root cause and development of a corrective action
- Issuance of shop repair paperwork
- Performance of the repair

The time, materials and overhead cost involved in the final item are obvious and don't escape consideration. But each of the eight items that *precede* the actual repair also add time, money and complexity to the cost of business. MRB actions can remain open and active from one to six months. During this entire time, out-of-sequence replacement parts must be manufactured to meet rate production and the customer's needs. The manufacturing schedule has been permanently disrupted.

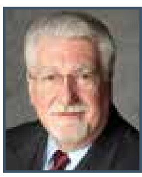
When we discuss the complexity and total cost of discrepant parts, then, another thing that is often overlooked is the aggregate impact on manufacturing. When a high-rate part or assembly is removed from the shop workflow, it must be replaced by another piece. Even when this is considered, it is often oversimplified by simply adding the direct cost of replacing the part. However, the impact of replacement goes far beyond that. Other indirect costs are associated with the following works in progress (WIP):

- Writing new shop paperwork, which takes a technician or manufacturing engineer away from other work.
- *Shop loading* — that is, inserting the replacement part into the workflow — *delays completion* of other parts that are processed on the same equipment.
- If the process includes a production bottleneck, all programs will be negatively impacted to an even greater degree.
- Inventory Control must stock, issue and reorder new materials for the replacement part.

The added WIP can increase overall cost by as much as 130%.

My company is attempting to address the impact of these often ignored but very real cost categories that erode profitability. We would like to ask *CW* readers to participate in a short survey. The survey's goal is to build a database of more detailed information that will enable the industry to recognize and begin to reduce the costs of advanced composites. In return for giving us 7 minutes of their time, we will send each participant the results of the survey after they are compiled, *and* we will provide an in-depth report on how 3D Predictive Data Analysis might impact your MRB. CW

Editor's Note: To participate in the survey and then receive an in-depth report on how 3D Predictive Data Analysis might impact MRB action, please visit:
sureveymonkey.com/s/3D-PDASurvey.



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Modeling and simulation: Is ICME the next composites breakthrough?

» In the July 2013 issue of *CW*'s predecessor, *High-Performance Composites* (*HPC*), I opined that the F-35 will be the last manned fighter aircraft. That was based on the indisputable fact that computing power will continue to grow significantly, making it possible for artificial intelligence to exceed the capabilities of human pilots in combat. I also suggested this would open up new opportunities for composites because a pilot-free aircraft could fly closer to the performance edge than a manned aircraft. In the October 2014 issue of *HPC's* sister publication, *Composites Technology* (*CT*), I followed that by bemoaning the slow rate of innovation in composites compared to that of the consumer-electronics and information-technology industries. The computing power in a single smartphone exceeds that of a room full of processing hardware from 30 years ago, yet we still struggle to overcome the inherent barriers to composites in infrastructure, automobiles and aircraft.

I've come to believe .... that computing power has the potential to truly transform the composites industry.

Having spent my career in the world of "making things," I have viewed computer-based modeling and simulation as a bunch of pretty pictures on a screen. One cannot drive to a restaurant in a virtual car or fly to Hawaii in a virtual airplane, I reasoned. (Well, you can, as in a video game, but you aren't physically traveling ... not while teleportation remains a concept in science fiction.) Real physical manufacturing — making tons of epoxy resin, laying up and curing prepregs, infusing textile preforms in a closed mold — is what puts composites into our bridges, our automobiles and the aircraft we fly. But then, most of my experience with computer modeling/simulation has been *sitting next to* a CAD or FEA expert, suggesting manufacturing-friendly draft angles or radii for a part, or proposing initial starting laminate schedules, then reviewing the outcomes of stress plots to determine where more material needs to be added or can be taken away. Yes, all pretty rudimentary stuff.

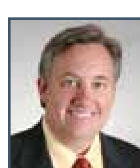
Over the past few years, however, I've been impressed with mold-filling analysis of high-pressure RTM, and with thermal modeling, which uses computational fluid dynamics of liquid heat transfer media, with improving accuracy in real-world validation. As a result, I've come to believe, in a big way, that computing power has the potential to truly transform the composites industry.

This past December, I attended *CompositesWorld's* Carbon Fiber 2014 conference (San Diego, CA, US), and I was able to drop in on BIOVIA, a subsidiary of the software giant Dassault Systèmes (Velizy-Villacoublay, France), probably best known for the CAD program CATIA. I was given a demonstration of a product called Materials Studio, which models substances at the molecular *and atomic* levels, and simulates how these materials interact and interface with other materials. Such tools are *already being used* by the pharmaceutical industry to develop new drugs, and several advanced composite material suppliers are looking at how they might use them to design new resins and improve fiber/matrix adhesion.

In *theory*, the properties mapped at a molecular level could be scaled all the way to full-sized parts, with the ability to accurately predict the performance of an aircraft wing or a vehicular bridge *without* having to build and test numerous coupons and sub-elements. The term Integrated Computational Materials Engineering, or ICME, has been coined to define this concept. Although I believe we are still some years away from being able to span this entire range, there are numerous computational tools out there today that — properly integrated — offer the ability to take basic materials data, assemble it, and help us to design both parts *and* manufacturing processes. This would reduce costs and enhance the acceptance of composites.

So, what will it take to make all this a reality? First and foremost, there needs to be considerable cooperation among the various simulation/design software companies. Competitors will need to collaborate to ensure that digital designs can be incorporated into models that predict crash behavior and then translate to simulation tools that predict manufacturing parameters, such as pressure, time and temperature. This, in turn, will ensure a good part without excessive voids or other defects. And that will involve common protocols for exchanging information. Hosting these disparate tools on a single platform, such as the evolving Composites Design and Manufacturing Hub (cdmHUB) at Purdue University, is a major step in getting all the software providers to work together.

Even more important is getting all us manufacturing "old-timers" to buy in and start *using* these software tools, especially the more sophisticated ones, to reduce the amount of empirical learning during the product development process. We can be a stubborn bunch, and will need to see lots of real-world validation of this method on the shop floor. I know *I'm* ready — and I believe a lot of others will be as well. CW



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Getting part dimensions right in composites molding

» Composite parts never have the same dimensions as the tool on which they are processed. Mechanisms such as tool dimensional change during heat up and residual stress buildup within the part during cure/solidification and cool-down are the cause. Many are familiar with results such as "springback," which is the closing of angles due to strain anisotropy[1]. This is true for all composite materials and processes — only the mechanisms differ between them and then, only slightly. Dimensional change is a problem if its magnitude is greater than the part's dimensional tolerance requirements.

Aerospace structure tolerances can be as tight as ±0.25 mm, and meeting tolerances this narrow can be difficult without a good dimensional-management strategy.

Anyone who has baked a cake knows that how it turns out depends not only on the ingredients in the batter but also the type of pan and oven, the pan's location in the oven, the baking temperature and time, and the cool down and removal from the pan. The same is true for composites processing. Dimensional management is a *systems level* problem, and many parameters affect cured-part dimensions. The systems parameters that affect dimensional change (and any other outcome in a composites process) can be divided into three broad groups related to the part, the tooling and the process[2]:

- Part: Geometry, material behavior and layup
- Tooling: Geometry, material behavior
- Process: Temperature, pressure, time and heat transfer

These factors all interact to determine the outcome.

If a tool is machined to the composite part's nominal engineering dimensions, dimensional measurements on multiple parts pulled from that tool will generally show a mean deviation from nominal and some variability around that mean. If the total deviation from nominal is less than the dimensional tolerances, dimensional conformance is achieved and no further action is required. If not, the part, tooling and/or process have to be modified to achieve dimensional conformance. This can be a costly and time-consuming iterative process, because it is difficult to anticipate the effect of system parameter changes if there is no predictive model.

It is increasingly unacceptable to depend on trial and error to achieve dimensional conformance, especially after the tool is made and full-scale part production has begun. Alternatives include depending on experience, consulting expert opinion and performing tests. The first two often fall short if the part and process is complex or deviates from the previous experience base. Test data are often of limited use because cured dimensions depend on part, tooling and process, which can make scaling of results from small test coupons to the full-sized part/process misleading and, thus, risky. A more effective option, particularly for large, complex structures, is computer simulation, where a physics-based model is generated and links systems parameters related to the part, tooling and process to the process outcomes — in this case, dimensional change.

To accurately predict that change, the model must include a high-fidelity description of the part, including its geometry, the layup and details of the composite material's *behavior* as its properties evolve during the cure/consolidation cycle. Also necessary is a good description of the tooling, including its geometry and its thermo-physical properties. Finally, the model must capture the *process*: temperature and pressure application over time, and heat transfer to the part and tool[3]. This type of *multi-physics process model* is, internally, fairly complex but can be relatively easy to set up and run if the right software-based solution package is selected.

There are several software tools on the market that can be used for design and simulation. For the purposes of our example, we used Dassault Systèmes' CATIA and ABAQUS design and simulation software with Convergent Manufacturing Technologies' COMPRO process simulation software (Fig. 1, p. 10). Fig. 2 shows the predicted temperature gradient

FIG. 1

FIG. 2

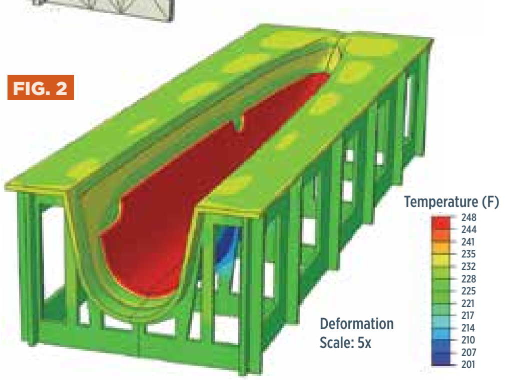
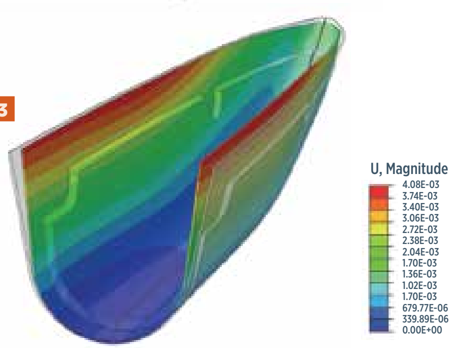


FIG. 3



Simulating change

Fig. 1: Finite element mesh of part and tool.
Fig. 2: Calculated temperature profile during heat-up and cure
Fig. 3: Calculated dimensional change.

Source | Convergent Manufacturing Technologies during heat ramp-up. When a process model is created for the part, tool and process of interest, it can be used to predict the expected mean dimensional change (Fig. 3) and to identify parameters that drive process variability. Often, the most effective way to address the part's mean dimensional change is by geometric compensation of the tool surface because it can be done without changing laminate or process parameters. Using the COMPRO/CATIA/ABAQUS solution set, geometric compensation of the tool can be performed *automatically* by transferring the calculated dimensional change back to the CATIA design environment and morphing the tool surface so that dimensional conformance is achieved. Altering the layup sequence and/or modifying the cure cycle are alternatives that can be developed and evaluated in the same simulation environment.

Once the system parameters have been adjusted to give a mean dimensional outcome that matches the nominal dimensions, the model can be used to identify and set bounds on the allowed variability of systems parameters, such that the dimensional variability of the part is within dimensional tolerances.

The technology and methodology presented here is routinely employed by large aerospace OEMs, and it is clear we have reached a tipping point: Powerful and effective process simulation tools and inexpensive, fast computational power are converging. Composites fabrication need no longer be treated as an art and should leave the domain of empiricism. Processing can be approached with the same analytical mindset and design and simulation tool sets as any other aspect of engineering. This is critical if we are to build large, complex composite structures that can compete with metal structures. The era of simulation-supported, knowledge-based composites manufacturing is here, and there is no turning back if we want to remain competitive. CW

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CW Business Index at 52.5 – US growth accelerates for a second month

With a reading of 52.5, the CompositesWorld Business Index for December 2014 showed that the US composites industry had expanded at a noticeably faster rate than in November. From July to October, during the past year, the industry had been virtually flat. But, in the last two months of 2014, it began to expand at a more rapid rate. Although the Index posted increases in November and December, the month-over-month rate of change remained relatively stable at about 3.0%. The annual rate of growth, however, decelerated in December and the three preceding months.

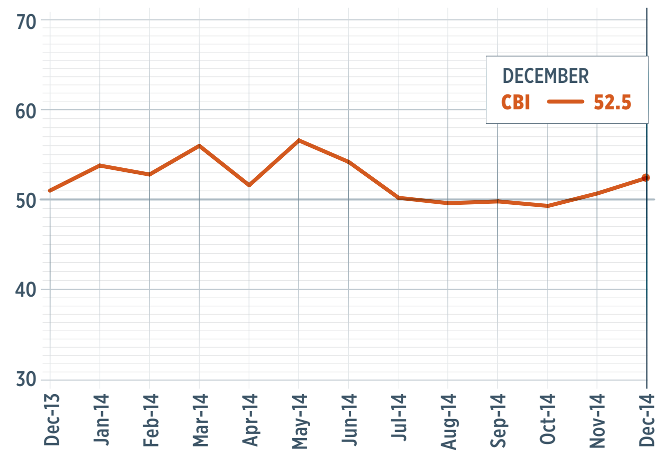
New orders grew for the 13th consecutive month in December. The rate of increase in new orders had been fairly constant during the previous six months. Production had expanded for 12 months. However, the production subindex grew at its slowest rate of the year in December. Backlogs expanded for the first time since May 2014. Annually, the rate of growth in the backlog index slowed for the fourth straight month. The trend in the annual rate of change, again, was a good indication that capacity utilization and capital equipment investment will increase into the second quarter of 2015. Employment continued to grow in December, increasing at its fastest rate since June 2014. Exports continued to contract, but the rate of contraction had slowed during each of the previous three months. Supplier deliveries continued to lengthen, increasing at their fastest rate since March 2014.

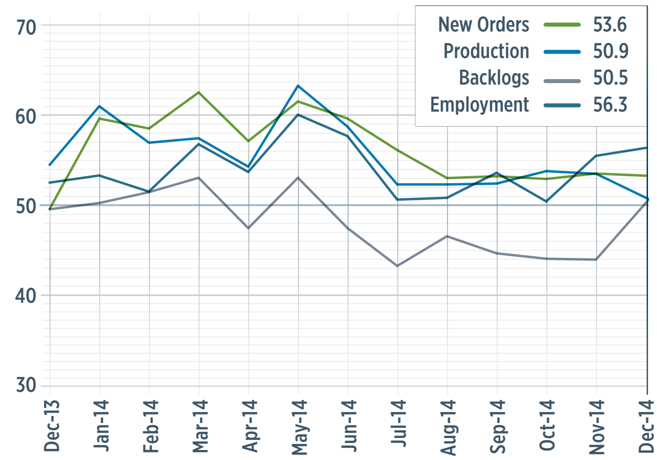
The rate of increase in material prices had slowed dramatically in recent months. As a result, the December material prices subindex was at its lowest level since September 2012. Prices received increased for the first time since September 2014. Prices received had been increasing, generally, since April 2014. Future business expectations increased sharply in December, for the second month in a row, and they reached their highest level since February 2014.

Composites manufacturing facilities with more than 100 employees expanded at a much faster rate in December than they had in November. Plants with 50-99 employees continued the consistent, solid growth they had experienced since June 2014. Facilities with 20-49 employees, however, contracted for the fourth month in a row, although the rate of contraction in December was the slowest of the four. Fabricators with fewer than 20 employees also continued to contract.

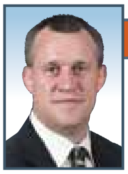
The North Central – West was easily the fastest growing US region in December. It had expanded during two of the previous three months. That area was followed by the West and the North Central – East regions. The South Central, Northeast, and Southeast sectors, however, all contracted at a moderate rate.

A CBI reading of >50.0 indicates expansion; values <50.0 indicate contraction.





Future capital spending plans contracted 25.7% compared to December 2013. Compared to the same period in 2013, they contracted in five of the previous six months, and the annual rate of change contracted for the first time since the Index began. CW



ABOUT THE AUTHOR

Steve Kline is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, OH, US), the publisher of *CompositesWorld* magazine. He began his career as a writing editor for another of the company's magazines before moving into his current role. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.

As the Airbus A350 and Lockheed Martin F-35 programs pass production milestones with noteworthy deliveries, wind energy gets a welcome positive forecast.

AEROSPACE

Airbus delivers first A350 XWB to launch customer Qatar Airways

Airbus (Toulouse, France) reported on Dec. 22, 2014 that it had delivered the first A350 XWB to Qatar Airways. Airbus claims that the A350 XWB, its answer to The Boeing Co.'s (Chicago, IL. US) mid-size, wide-body commercial airliner, the 787 *Dreamliner*, embodies the most advanced technologies and breakthrough innovations in aerodynamics, composites and aircraft systems. Reportedly 52% composite by weight (the 787 is roughly 50%), the A350 is powered by Rolls-Royce Trent XWB engines, which are expected to be more fuel efficient and quieter than previous turbofans. Airbus predicts the plane will provide Qatar and its other airline customers with unprecedented operating efficiency and cost effectiveness. The plane also features a slightly wider, more spacious cabin than the 787.

"Receiving the A350 XWB as global launch customer is a very proud moment for Qatar Airways, and after much anticipation, I am delighted that the day has come when we welcome this latest-generation aircraft into our rapidly expanding fleet," says Qatar Airways Group chief executive, Akbar Al Baker. "I am ... delighted that Qatar Airways will be leading the way in the aviation sector in offering our passengers the opportunity to travel on board the most modern of airliners in the sky."

Source / Airbus

Fabrice Brégier, Airbus president and CEO, says, "Handing over the first A350 XWB represents a significant step in Airbus and aviation history. It's a perfect match, to be handing over the first of an all-new, world-class aircraft to a leading, world-class airline."

Congratulations to Airbus on the launch came in from several composites industry suppliers, including Hexcel (Stamford, CT, US), which supplies carbon fiber prepreg; GKN Aerospace (Redditch, UK), the maker of A350 wing and engine structures; Spirit AeroSystems (Wichita, KS, US), the manufacturer of the plane's fuselage and wing structures; and TenCate Advanced Composites (Nijverdal, The Netherlands), the supplier of the plane's thermoplastics.

Lockheed Martin celebrates F-35 Joint Strike Fighter's 36th delivery during 2014

Lockheed Martin (Ft. Worth, TX, US) reported on Dec. 22, 2014, that the US Department of Defense (DoD) had accepted its final F-35 *Lightning II* delivery of the year, meeting the program's 2014 production goal of 36 aircraft. That brought the total number of operational aircraft delivered to the US and partner nations to 109 since the program's inception. The 36th delivery — aircraft CF-19 — was the first F-35C (aircraft-carrier variant) delivered to the US Marine Corps. The jet will be assigned to the US Navy's VFA-101 "Grim Reapers" Fighter Squadron, 33rd Fighter Wing, Eglin Air Force Base, FL, US.


Source / Lockheed Martin

"Delivering the most F-35s in program history is a clear demonstration of our growing stability and ability to ramp up production," says Lorraine Martin, Lockheed Martin F-35 Program general manager. "Congratulations to the entire government-and-industry team for their work to deliver 36 aircraft."

View a four-minute video on the F-35 program, narrated by Martin, online | **short.compositesworld.com/F-35-2014**

A complete list of F-35 deliveries, to date, appears with the online article | **short.compositesworld.com/F35Goal14**

ENERGY

Wind Energy forecast: Big increase offshore, despite steep European drop in 2016

The global offshore wind market has grown, on average, more than 30% annually in the past 5 years: Grid-connected capacity, worldwide, was expected to be more than 9 GW by the end of 2014 — equivalent to 2.7% of global wind power capacity. Globally, 51% growth is expected in offshore wind capacity in 2015. However, sustained growth in the Asia-Pacific region during 2016 will not be able to balance a sharp decline in new grid-connected capacity expected in the UK and Germany. That's the view of the current situation presented by MAKE Consulting (Aarhus, Denmark and Chicago, IL, US) in its new report, *Global Offshore Wind Power 2014*, but during the remainder of the coming decade, offshore wind is expected to show strong long-term growth rates. MAKE says the market will grow at a 22% compound annual growth rate (CAGR) from 2014 to 2023. By 2023, total offshore wind capacity could reach a staggering 82 GW, equivalent to 9.3% of global wind power capacity. By then, Asia-Pacific wind farms will account for 40.4 GW of this capacity and will have caught up with European developments, which will account for 39.4 GW. China will be the principal growth driver in Asia, but Japan, South Korea and Taiwan will make notable contributions. Annual installed capacity in Europe will vary from 3 to 5 GW in the 2017-2023 timeframe, supported by national and EU polices.

Growth on a smaller is predicted for the Americas. The US, for example, will account for only 2.2 GW of the expected global grid-connected base in 2023.

MAKE notes that clarity in terms of the post-2020 regulatory framework is a need if the offshore wind industry is to sustain the momentum of cost reductions and growth.

MAKE expects the levelized cost of electricity (LCOE) from offshore wind to fall from the current level of €150 (US$179) per MW/hr to €110 (US$131) per MW/hr in 2020, slightly above the €100 (US$119) per MW/hr target set by several major industry players. By 2025, MAKE forecasts LCOE will drop to €84 (US$100) per MW/hr. Offshore wind, therefore, will undergird wind energy's progress toward grid parity.

Key drivers for the cost reduction include scaling and industrialization of the offshore wind supply chain, technology improvements related to larger turbines and wind turbine manufacturing plants, lower-cost substructures, higher technical availability, and reduced cabling cost combined with expected lower capital, lead-time, operations and maintenance costs.

These projections and more are contained in MAKE's 90-page report, illustrated with more than 150 charts, tables and graphs. It's available through the MAKE Consulting Web site | **www.consultmake.com**

TPI, Vestas reach agreement on wind blade supply for China

TPI Composites (Scottsdale, AZ, US) announced on Dec. 19, 2014, that it had signed a multi-year supply agreement with Vestas Wind Systems A/S (Aarhus, Denmark) to provide blades for the V110 wind turbine from TPI's factory in Dafeng, China.

Vestas launched its V110-2.0MW wind turbine in the China market in October 2014.

"We are thrilled that Vestas has selected TPI to be its first outsource partner of Vestas-designed blades," says Steve Lockard, president and CEO of TPI Composites. "From Dafeng, China, we will supply V110 blades to China and export markets in a reliable and cost-effective manner."

TPI has been building wind blades to international quality standards in China since 2008. The company's Dafeng plant measures 35,000m^2 and is located 250 km north of Shanghai, in Jiangsu Province.

ENERGY

UMaine tests massive wind blade for Gamesa

The University of Maine's (UMaine) Advanced Structures and Composites Center (ASCC, Orono, ME, US) has completed static testing of a 56m wind turbine blade for turbine manufacturer and wind farm developer Gamesa (Zamudio, Vizcaya, Spain). The blade was manufactured in North America and delivered to UMaine in late August 2014.

"We are honored to have served one of the world's leading wind turbine manufacturers," says UMaine's Composites Center director Dr. Habib Dagher, "This is the biggest structure we have tested to date, extending nearly 80% of the length of our blade test lab."

"Our engineers, technicians, and students did a great job designing, building and operating the equipment needed to safely rotate and test the 56m blade," said John Arimond, who joined the UMaine Composites Center in 2013 after 28 years in industry, most recently as the CTO at a New Zealand-based manufacturer of 500-kW wind turbines.

Juan Diego Díaz, Gamesa´s marketing director, adds, "We are excited to be partnering with UMaine for blade testing. North America was a logical place to conduct this important step in our product development, supporting our growing commercial opportunities in that region and globally. We were impressed by the testing quality, safety and attention to detail provided by the UMaine team in successfully testing our blade."

The University of Maine's 9,300m^2, US$110 million, ISO 17025-accredited laboratory has completed more than 500 product-development and testing projects over the past five years.

Learn more about UMaine's ASCC online | **www.composites.umaine.edu**

Source / UMaine

ELECTRONICS

China-based molder markets mass-production capabilities via US branch

Keyrou, the manufacturing arm of Xin Xiu Electronics Co. Ltd. (Dongguan, Guangdong, China), has produced more than 13 million Kevlar composite components used in Motorola Razr and Razr MAXX HD cellphones. *CW* got acquainted with the company, when it introduced its Evutec concept — with design and marketing operations in Walnut, CA, US — CAMX 2014 (Oct. 13-16, Orlando, FL, US).

Evutec showcases Keyrou's unique design and composites technology capabilities. Evutec director of design David Rojas explains, "Most structures made for phones and electronics generally use 3D molding, which produces C-shaped edges [radii] because they are easy to remove from the production tools." Keyrou has developed its proprietary 6D process, that can achieve full encapsulation of all edges. According to Rojas, the "return flanges are gorgeous. It uses laser cutting to remove the parts and enables seamless parts with flawless finish, requiring no further gluing or assembly at volumes of up to 10,000 per day." Rojas adds that Keyrou is exploring where its advanced composite molding technologies might enable new applications, "for example, automotive, but also aerospace and military, where fibers like Kevlar are already well-proven."

Read more about Keyrou's 6D process online | **short.compositesworld.com/Keyrou6D**

Source / Keyrou

CW MONTH IN REVIEW

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

Wind industry policy uncertainty affects global supply chain
01/14/15: Report discusses industry trends and wind blade outlook, including manufacturing move out of Europe and new innovations to reduce cost of energy.
short.compositesworld.com/FTIWind15

Local Motors teams with ARPA-E for lightweight future vehicle design
01/12/15: $150,000 prize for conceptual design that lowers vehicle curb weight while meeting or exceeding current US automotive safety standards.
short.compositesworld.com/LocalARPA

Ford introduces composites-intensive Ford GT carbon fiber supercar
01/12/15: The all-new *GT* ultrahigh-performance supercar features a carbon fiber passenger cell and carbon fiber body panels hung on aluminum subframes.
short.compositesworld.com/NewFordGT

Recaro to introduce new composites-intensive automotive seat
01/12/15: The new modular seat design uses a carbon fiber sandwich construction and is expected to begin series production in 2016.
short.compositesworld.com/RecaroSeat

Mitsubishi to integrate PAN- and pitch-based carbon fiber businesses
01/12/15: With the integration, Mitsubishi will create a new organization by April 1 and hopes to enhance its position in the carbon fiber industrial market.
short.compositesworld.com/MitsuPandP

Ford, DowAksa accelerate automotive carbon
01/10/15: The companies are working to overcome the high cost of carbon fiber, while developing a viable, high-volume manufacturing process for automotive applications.
short.compositesworld.com/FD-autoCF

Janicki Industries to get SeaSport Commander product line back into production
01/06/15: Laser scanners and CAD software help rebuild legacy tooling lost in fire.
short.compositesworld.com/SeaSport

NASA selects four commercial space partners
01/05/15: ATK Space Systems, SpaceX, ULA and Final Frontier Design are selected for an unfunded partnership to develop new space travel capabilities over the next five years. short.compositesworld.com/NASA-4

XCOR *Lynx* suborbital spacecraft nears final assembly
12/23/14: US-based XCOR Aerospace's *Lynx* suborbital spacecraft is nearing final assembly as shop crews set up to bond the carry-through spar on the rear of the fuselage. short.compositesworld.com/XcorLynx

Toyota fuel-cell vehicle to use Toray carbon fiber
12/23/14: Carbon fiber thermoplastic composites will be used in the vehicle floor, and carbon fiber thermoset composites will be used in the high-pressure hydrogen tank of the forthcoming Toyota *Mirai*. short.compositesworld.com/FCV-Mirai

Boeing breaks ground on St. Louis composites facility
12/22/14: The $3,345m^2$ plant in St. Louis, MO, US, will fabricate wing and empennage parts for the Boeing 777X commercial aircraft, starting in 2017.
short.compositesworld.com/BoeingStL

MARINE

Composite commercial fishing boat rebuild: Third time's the charm

A 35m fishing boat was recently rebuilt by Mundal Boat (Sæbøvågen, Norway). Not unusual. But what's newsworthy is that it wasn't the first time, but the *third*. The *M/S Bluefin*, owned by Nye Bluefin AS, in Nekkøy, was built in 2000 and then expanded twice, in 2005 and 2006. In 2013 a decision was made to further extend the boat's length, adding 7.8m, amidship, to increase the capacity of its hold.

A specialist in large vessels of sandwich composites, Mundal Boat handled the original construction and rebuilds with materials from DIAB International (Laholm, Sweden). A *purse seiner*, the craft bears a net (the *seine*) that is cast in a circle around a school of fish, then drawn to a close like a *purse*. The original was cored with DIAB's Divinycell foam to withstand sea weather and have the strength to tow/hoist the catch economically. More durable than a wooden or steel-clad counterpart, the boat also is lighter, enabling greater speed and fuel economy with a comparable engine.

The third extension, designed again by Maritime Engineering AS (Isdalstø, Norway), involved adding three new cargo holds that increase capacity to $300m^3$. In addition, Mundal added a new deckhouse on the port side and an extended dayroom that now accommodates a crew of 11.

Read an expanded version of this article online | **short.compositesworld.com/Bluefin**

RECREATION

STIGA Sports to apply carbon fiber fabric to table tennis paddles

STIGA Sports AB (Eskilstuna, Sweden), a market-leading brand in table tennis, reports that it has turned to Oxeon's (Borås, Sweden) TeXtreme spread-tow carbon fiber reinforcements to help maximize performance of its blades (paddles).

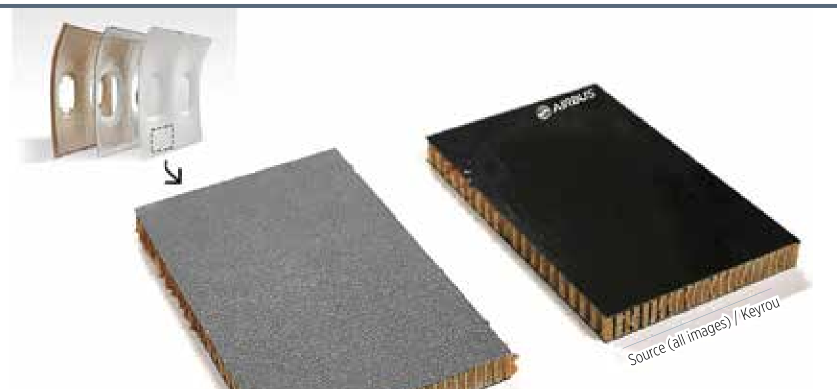
"We are thrilled to have entered this partnership with STIGA and to move into another area where the unique benefits of TeXtreme technology come to use," says Henrik Blycker, CEO of Oxeon AB. "With our knowledge and flexibility in producing the best possible carbon fiber reinforcements, and STIGA's expertise in table tennis, we have set up a fruitful cooperation, hopefully leading to important victories in the future."

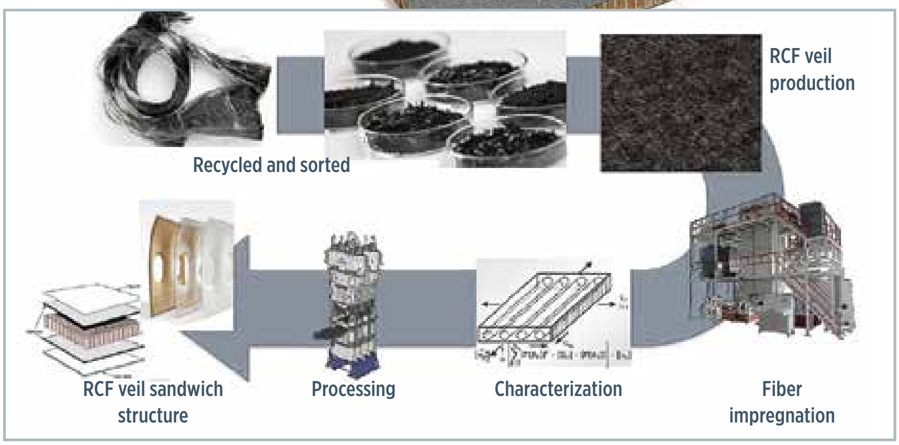
"The partnership with TeXtreme is a major step for us in the constant search for bringing the most innovative products in the sport," says Mats Bandstigen, CEO of STIGA Sports AB, adding, "The proficiency of STIGA's R&D department, combined with state-of-the-art manufacturing procedures, makes it possible for STIGA to constantly provide new, innovative and unsurpassed products. The combination of the finest wood, high-end TeXtreme material and craftsmanship make STIGA's blades the best that nature and science can offer."

The retail launch of the new blades was set for early 2015.

AEROSPACE

Recycling carbon fiber for structural applications





The Composite Technology Center (CTC, Stade, Germany) has been working with Stade-based CFK Valley Recycling and CarboNXT GmbH (Wischhafen, Germany) toward the goal of developing recycled carbon fiber (RCF) for aircraft applications. Specifically, the collaborators want to demonstrate a full-scale passenger cabin interior sidewall panel (see photos at right). CTC researcher Tassilo Witte leads the team, and is currently characterizing not only RCF materials but also the composites made from them, performing a full battery of mechanical tests (tensile, compressive, flexural, etc.) on the filament, filament bundle, monolithic laminate, sandwich laminate and, finally, small- and full-scale components.

"This is the classic test pyramid approach used in aircraft," explains Witte, "because it characterizes a material so that engineers can then design with it."

Key results, thus far, include fabrication of RCF/epoxy laminates that, for most load cases, surpass those made with virgin E-glass fibers. The effort is on track to build and test full-scale sidewalls by 2016.

Witte is pursuing, in parallel, development of his recent patent that addresses recycling of continuous carbon and glass fibers from filament-wound pressure vessels. The potential impact for "greening" such composites is reportedly huge, given that there are an estimated 374,000 composite compressed natural gas (CNG) tanks produced annually for the global automotive industry alone, and, at a forecast compound annual growth rate (CAGR) of 10.4%, that figure is expected to reach 613,000 CNG tanks per year by 2019.

Read more about RCF work at CTC online | **short.compositesworld.com/RCFStruc**

FIG. 1: Braided Web for Gears

A typical steel spur gear is shown on the left. A hybrid gear, with a composite material web, is shown on the right. The composite material is a QISO slit carbon fiber braid from A&P Technology, prepregged with an epoxy from TenCate Advanced Composites.
Source | A&P Technology

New aerocomposites niche: Helicopter transmission gears?

A NASA study shows that steel/composite hybrid gears save significant weight, and could mitigate vibration-related noise.

By Sara Black / Technical Editor

» Among the US National Aeronautics and Space Admin.'s (NASA, Washington, DC, US) many missions is The Rotary Wing Project, established to increase helicopter speed, range and payload, while decreasing noise, vibration and engine emissions. Myriad projects are contributing to these overarching goals. Among them is one funded through a Small Business Innovation Research (SBIR) contract that is focused on designing better gears for helicopter drive systems. A team of composite materials specialists is pursuing that end. Headed by NASA Glenn (Cleveland, OH, US) research engineers Dr. Gary Roberts and Dr. Robert Handschuh, the team includes members from the US Army Research Laboratory (Adelphi, MD, US) and braided reinforcements supplier A&P Technology Inc. (Cincinnati, OH, US).

Why *gears?* A helicopter's drive system (engine, vertical driveshaft and geared transmission) makes up 10-15% of the aircraft's total empty weight and is a major contributor to helicopter noise due to vibration. Roberts explains that newer but all-metal multi-speed transmissions could be employed to improve helicopter speed and efficiency but would add significant weight and wouldn't address the need for acoustic damping. He asserts, however, "There's potentially a very high payoff in … reducing vibrations near the source, which is primarily at the gear mesh point."

Why, then, composites? "The reason we thought this was a good project," explains Mike Braley, A&P Technology's VP of application development, "was that if you replace some of the metal with composites, you could interrupt the vibration transmission pathway from the gear teeth to the center shaft, which will help reduce overall noise, and at the same time reduce the gear's weight without sacrificing good load performance."

Roberts and his team, therefore, decided to investigate how composites incorporated into transmission gears could reduce not only weight and vibration but also, ultimately, maintenance and repairs, because they would have lower densities and higher damping coefficients than conventional steel gear alloys. During the project's first phase, the feasibility of three metal/composite attachment concepts was investigated, small spur gear prototypes were built (using one of the concepts) and then tested. The ongoing second phase involves investigation of larger, optimized gears and an all-composite web/hub/shaft concept, along with vibration testing.

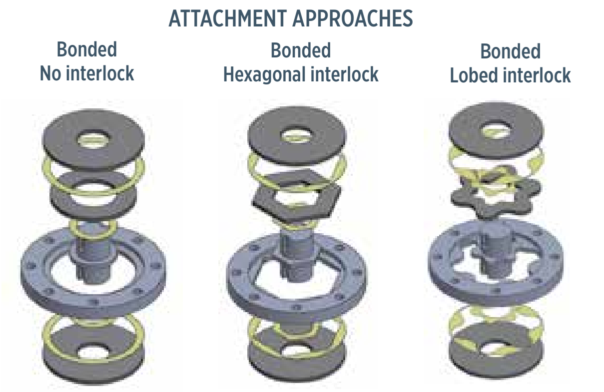
A composite/metal hybrid

What helicopter transmission gears lack in glamor they make up for in severe service (exposed to hot oil and high loads) and their designation as highly proprietary technology. Helicopter OEMs closely protect exact gear tooth profiles, Roberts explains, adding, "Currently, gear teeth must be made with gear steel and special alloys, because of the very high loads generated when gears mesh together." For this reason, the project team looked, initially, at hybrid designs in which composites would be used only in the gear's flat inner web, with steel still constituting both the gear teeth and the inner hub. Fig. 1, above, shows one of the small "spur" gears built for the project.

> What helicopter transmission gears lack in glamor they make up for in severe service ….

"Because the gears are rotating structures, an important property requirement for the feasibility study was that the constant-thickness composite web section had to exhibit the same stiffness in all in-plane directions," Roberts explains. That led Roberts to choose A&P's trademarked QISO braided triaxial fabric, essentially a braid that is slit open to form a flat broadgood. "A 0/+60/-60 triaxial fabric has the quasi-isotropic property that we needed," says Roberts, "and with QISO, we didn't have to manipulate multiple uni or woven plies."

The team specified QISO "heavy" fabric, made with standard-modulus 12K T700S-50C carbon fiber supplied by Toray Carbon



- Designed with equal bonded surface area (inner ~16 cm^2 per side; outer ~37 cm^2) for each approach
- Strength of attachments measured under torque load with acoustic emission to detect damage
- Data useful for calibration of models that will be used for structural optimization

FIG. 2: The Steel-to-Composite Interface

Three attachment concepts were tested, to combine the composites with the steel. The concept at left relies only on adhesive film, while the center and right-side concepts use interlock features for better load transfer. Source | NASA

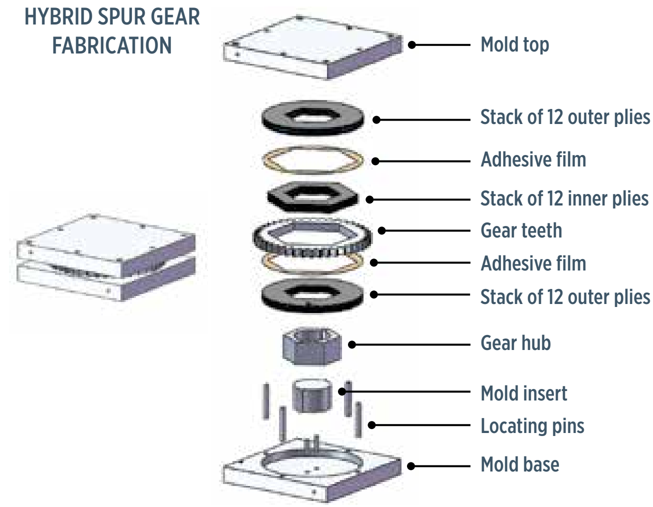


FIG. 3: Hybrid Spur Gear Assembly

This exploded view shows the fabrication elements employed by A&P Technology to produce the hybrid spur gears. The pre-cured laminate disks (shown in dark gray) were waterjet cut to the shapes shown, and the assembled gears were press-cured. Source | NASA

FIG. 4: Testing the Hybrid Gear for Durability

This test gearbox was employed for endurance testing of the gears. The hybrid steel/composite gear is on the left. After 1 billion cycles in the gearbox, no damage nor delamination was detected. Source | A&P Technology

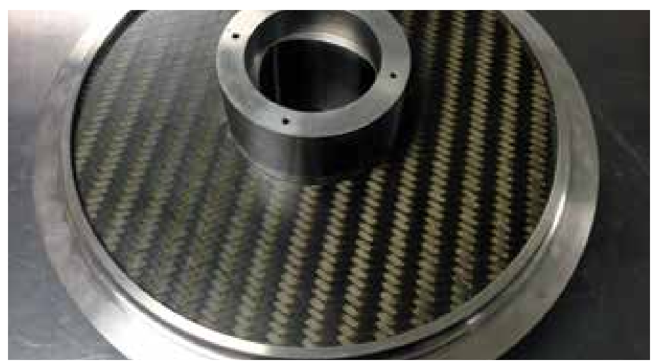


FIG. 5: Next Step: Larger "Bull" Gears

A&P Technology is currently fabricating larger "bull" gear hybrids for ongoing testing of attachment approaches and performance. This prototype bull gear web, (minus teeth) is 254 mm in diameter. Source | A&P Technology

Fibers America Inc. (Flower Mound, TX, US), with an areal weight of 536 g/m^2. Roberts explains that the standard-modulus fiber was adequate for the feasibility study but a different, optimized fiber might be used in the future. For now, says Braley, "The standard-modulus fiber in this balanced configuration is a good trade-off between performance and cost." The fabric's architecture featured two fiber ends in the axial direction, and one in each bias direction (±60°). The finished fabric was sent to TenCate Advanced Composites USA Inc. (Morgan Hill, CA, US) for prepregging.

The prepreg resin would have to endure the environment within the helicopter gearbox environment, where oil temperature can reach 150°C. Braley says epoxy was more than adequate for the Phase I feasibility work and also fit well within the project's cost and schedule restraints.

With materials selected, a scheme for fabricating the hybrid gears — attaching the composite web to the steel shaft and outer, toothed ring — had to be developed. Three concepts were evaluated using quasi-static torsional tests (see Fig. 2, above). One involved pre-cured laminates, cut to shape and then bonded to each other and to the steel elements with film adhesive. Here, the gear relied for its strength on the adhesive. In another concept, the hexagonal, innermost laminate was pressed into the matching hex shape of the steel rim and shaft, providing an interlock feature in addition to the adhesive for a stronger connection. In the third concept, lobed geometry was developed for even better load transfer.

"We tested all three attachment concepts," says Roberts, noting that they were designed to have equal bondline surface area. He adds that another project partner, Altair Engineering Inc. (Troy, »

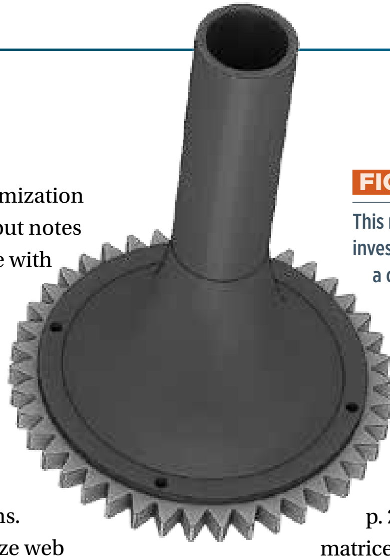


FIG 6: All-composite Gear Concept?

This rendering shows a conceptual all-composite gear under investigation that potentially could cut gear weight by 50% vs. a comparable steel gear. Source | A&P Technology

MI, US), is working with A&P on a topology optimization model that will help guide design refinements, but notes that the hexagonal interlock attachment scheme with a constant (not yet optimized) web thickness, was used for simplicity's sake, in the initial hybrid spur gear evaluation. "The laminate disks were overdesigned for structural loads in the initial tests since the primary purpose of these tests was to identify potential problems with material and attachment endurance in a gearbox environment," Roberts explains. "It will be interesting to use the model to optimize web thickness profile and attachment geometry for even greater weight savings in future hybrid gear designs."

The A&P team, led by application engineer Nate Jessie, fabricated the attachment test elements and the demonstration spur gears in a press-molding process, after first laying up 12 plies of QISO prepreg. Jessie explains that each ply was rotated 60° during the layup, despite the QISO's already balanced weave, to ensure that the laminate would be "fully isotropic." The laminates were ovencured, then waterjet trimmed to net shape. The gears were fabricated in the sequence shown in Fig. 3 (p. 21), with a second heated press cycle to cure the film adhesive. "There are three 12-ply QISO laminates in each gear; two outer and one inner, assembled with adhesive film," explains Jessie.

+ LEARN MORE

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

To see if they could stand up to the heat, vibration and torque loads, the press-cured, bonded spur gears were subjected to endurance tests in a gearbox operated at 10,000 rpm and nearly 500 in-lb of torque. After 1 billion cycles, there was no detectable gear damage nor composite delamination (see Fig. 4, p. 21).

In separate static tests, larger versions of the gears (without gear teeth) were used to evaluate each of the three attachment concepts under similar conditions and to provide data for validation of structural optimization analysis methods, says Roberts. The larger structures were mounted on a test fixture to which accelerometers were attached, so that acoustic emission "events" (sounds that indicate breakage of the adhesive bonds) could be monitored during load application. The static results showed that, at room temperature, bond failure of the gear web occurred at about 50,000 in-lb of applied torque for the first concept, at about 55,000 in-lb for the hexagonal interlock design, and at 68,000 in-lb for the lobed concept. The hexagonal and lobed interlock designs not only performed better than the adhesive-only design but also provided ongoing load-carrying ability after bond failure. The lobed interlock was the last to disbond, failing at about the 5-minute mark.

Although the results of modal analysis and free vibration tests were inconclusive, Roberts says, "We believe that composites will give us the ability to tailor the natural vibration frequency, for better damping." Toward that end, the team will alter the laminate thickness, adjust its stiffness by using different carbon fiber types, and might add visco-elastic material. During the project's second phase, the team will fabricate and test scaled-up steel/epoxy composite hybrid "bull" gears (see Fig. 5, p. 21), and bismaleimide (BMI) and polyimide (PI) matrices will be investigated. "Some gear applications require continued operation for a specific time period if loss of lubrication should occur," Roberts reports, so the gear laminate might need a high-temperature-capable resin "to survive the thermal transient after loss of lubrication, when we go into actual field trials."

A&P will deliver several bull gears for testing in NASA's High Speed Helical Gear Test Rig. During additional structural tests of the attachment approaches, high-speed, high-resolution digital image correlation methods will be used to evaluate local deformation near attachments during operation. After this testing is completed, says Roberts, the team will be better able to assess the possibility of commercializing hybrid gears in rotorcraft.

Positive results, more work

So far, composite material and a steel/composite adhesive bond have proved capable of handling temperatures, loads and oil exposure within a gearbox. Static testing shows the mechanical interlock features provide sufficient strength for torsional loading. Hybrid spur gears have shown nearly 30% weight savings compared to all-steel gears, *without* design optimization. And A&P is investigating the use of composite material in the gear hub and connecting shaft to form an integrated web/hub/shaft in composites with steel gear teeth. Roberts anticipates that this design could yield 50% weight savings (Fig. 6, above). The braided preform and resin infusion process are under development. "An initial design and prototype will be delivered at the end of the contract," he predicts. "A&P is working out some very intricate fiber architecture that results from the shape of the preform, and how that architecture can handle the required loads."

But Roberts contends, "We are just beginning to explore the possibilities." The helicopter gearbox is a challenging environment. "As a result, flight qualification for rotorcraft will be very expensive and take a long time. But," he adds significantly, "I believe there could be other commercial/industrial applications for gears of this type in the nearer term." CW

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■ Thermoplastic Composite Pressure Vessels

The U.K-based DuraStor and followup HOST consortiums were mobilized to find a safe and efficient way to store enough hydrogen or natural gas under high pressure to give fuel-cell-powered electric vehicles the equivalent driving range offered by conventional liquid petroleum fuels and internal combustion engines. Thermoplastic composites have provided a likely solution. Preliminary testing on this carbon fiber/acetal tape-wound vessel (shown here partially and fully wound) indicates the completed vessel meets or exceeds all requirements. Source | DuraStor Consortium

Thermoplastic composite pressure vessels for FCVs

UK consortiums address durability, weight, cost of high-pressure tanks for hydrogen fuel-cell-powered vehicles.

By Peggy Malnati / Contributing Writer

» Most of the world's automakers are scrambling to increase fuel efficiency and/or reduce greenhouse-gas emissions ahead of tough regulations that are phasing in between now and 2025. Toward that end, these OEMs are reducing vehicle mass and exploring alternative powertrains options (see "Learn More," p. 26). One of the most intriguing of the latter is the fuel cell. Although major technical and logistical hurdles must be cleared before we see widespread deployment, fuel-cell vehicle (FCVs) are under development or already in road testing. Fuel-cell electric powetrains are of great interest because the only combustion byproducts of their two most common fuels — hydrogen (H_2) and compressed-natural gas (CNG) — are water and heat, making zero-emissions vehicles (ZEVs) possible.

One of the biggest hurdles is H_2 fuel storage. H_2 has been handled safely by industry for decades and can be produced locally, nearly anywhere, from diverse inputs (biomass, coal, geothermal, hydroelectric, nuclear, solar, wind, electrolysis of water, or even CNG). This flexibility is highly beneficial from a cost, energy security and lifecycle analysis standpoint. But this extremely light gas (14-times lighter than air) has three times more energy density by weight but far less energy by volume than conventional liquid petroleum fuels. Further, the hydrogen molecule is the world's smallest, so permeation resistance of storage containers becomes a real concern, lest fuel leak out. It's very difficult, therefore, to package H_2 in the small spaces available in most cars in sufficient quantity to duplicate the 500 km-per-tank driving range of today's petrol-powered cars, especially when the goal is to do this without boosting vehicle mass. Although there are alternatives (see "H_2 storage methods," on p. 17), the most practical and least costly onboard H_2 storage method is as a compressed gas at working pressures of 20-70 MPa in tanks that must test out to a burst strength of twice their rated pressure.

Storage challenges

Today, four types of pressure vessel are available for H_2 storage (see "Learn More"). Type I (all-steel) containers are heavy and bulky. Type II tanks (steel or aluminum liners hoop-wound with carbon fiber/epoxy) are lighter but cost more. Each is capable of up to 30 MPa working pressures and used for bulk transport or stationary gas storage at refueling stations. Similar to Type II tanks, but fully wound with carbon/epoxy composite, Type III tanks are even lighter but more costly, withstand higher working pressures (to 82.5 MPa, with aluminum liners) and are primarily used for H_2 or CNG storage on commercial trucks. Type IV tanks feature either high-density polyethylene (HDPE) or rubber liners fully overwrapped with carbon fiber/epoxy. The lightest but most costly, they offer performance similar to Type III tanks.

Unfortunately, certain metals and metal alloys tend to absorb H_2, leading to embrittlement that reduces tank durability. And hybrid-material tanks are prone to fatigue at the mixed-material interface, which can limit useful life. Further, the epoxy matrix, a thermoset, complicates end-of-life reclamation, an added headache for automakers selling into the European Union. Generally, then, available tanks deliver insufficient weight-to-cost benefit, store too little fuel for adequate driving range, are difficult to recycle and/or lack sufficient durability for mass use on automobiles.

Building a better tank

In 2010, a multi-partner, multi-year research program called Low Cost, Durable Thermoplastic Hydrogen Storage Tanks, or DuraStor, was formed to address these problems by investigating a drop-in replacement for Type IV tanks. Partially funded by Innovate UK (Swindon, Wiltshire, UK), DuraStor ended in early 2014, but a UK-only program called Hydrogen – Optimisation of Storage and Transfer (HOST) picked up where DuraStor left off in mid-2014, funded in part by the UK Technology Strategy Board, with the same charter and a few changes in members (for a list of consortium participants, see "Learn More"). Members of both programs reportedly were chosen not only for their technical expertise but also their willingness and capability to form a viable supply chain should research lead to a commercial product.

After a market study yielded initial pressure vessel design specifications, the DuraStor team moved on to materials and processes. A patent survey showed that most intellectual property in this arena involved thermoset composites, but one team member familiar with the permeation resistance of inexpensive thermoplastic liner materials convinced the team to explore them, because they not only weigh less than metals but also process faster and offer greater impact strength and reprocessability/recyclability than thermosets. Further, thermoplastics can be remelted, offering the opportunity to produce liner and overwrap separately, then join them to create a monolithic tank that could avoid fatigue issues seen in existing metal/composite hybrids and facilitate recycling. By eliminating all metals except for coupling hardware, which could be isolated, hydrogen embrittlement and galvanic corrosion could be reduced or eliminated.

"In the lead up to these programs, we had many discussions with automakers who clearly were interested in fuel-cell technology, but lacked confidence in the long-term performance of current hydrogen-storage vessels," explains Dr. Matthew Turner, head of R&D, EPL Composite Solutions Ltd., project lead for the DuraStor and HOST programs. "Our consortium members believe that thermoplastic composites can offer better durability than thermosets."

DuraStor evaluated three semi-crystalline thermoplastic resins (supplied by consortium member Celanese, Dallas, TX, US) known for good mechanical properties and high chemical and permeation resistance: polybutylene terephthalate, polyphenylene sulfide, and polyoxymethylene (POM, or acetal). POM was chosen based on prior work by two team members and its long history of use in automotive fuel-handling components and low-pressure fuel storage. The liner would be neat POM to optimize permeation resistance, but the overwrap had to be reinforced to maximize the vessel's hoop strength and burst- and puncture-resistance. The team selected continuous-strand carbon fiber rather than E-glass, because the former offers greater strength-to-weight and is already used, with epoxy, by many tank manufacturers. Unidirectional tapes, considered the most practical fiber form, ensured very low void content and no dry spots, both critical to permeation resistance.

> "Our consortium members believe that thermoplastic composites can offer better durability than thermosets."

Process selection began with the hollow liner. Because leakage was unacceptable, the team wanted to produce liners in one piece rather than join multiple parts. To manage costs, the process needed to be inexpensive at research volumes and scalable to automotive production volumes. Blowmolding, casting and rotomolding (rotational molding) were considered. The latter was selected based on its low tooling costs; its low forming stresses (which reduce post-mold warpage); its ability to produce large components with good surface finish and controlled wall thickness; and the fact that threads could be molded in for coupling hardware (which allows fuel flow in and out) and inserts could be used to minimize post-mold finishing. Although rotomolding cycles are slower than most other thermoplastic forming methods, family tools and use of rotary stations can increase output at a relatively low cost vs. other options.

Filament winding, already used by tank manufacturers, would be the overwrap process but the team would likely have to modify winding heads to handle preimpregnated thermoplastic tapes.

With materials and processes in hand, the team conducted parallel testing projects. Some members did small-scale mechanical testing (per ISO 527-3, ISO 178 and ASTM D3410M) and permeation testing (per ISO 5869) on neat, injection molded POM and vacuum/autoclave-cured POM/carbon laminates. Another group designed the liner, its coupling hardware and the rotomolding tool. Several liner designs were trialed between 2011 and 2013. Some molded liners from each batch were cut up and subjected to further mechanical and permeation testing. It was important to validate the accuracy of preliminary tests results — which were conducted on injection-molded samples with a POM grade and additive package designed for injection molding — by testing samples produced in the rotomolding process, using a similar but not identical POM grade with a different additive package. The correlation was quite good and the team concluded that formulation and processing differences didn't adversely affect polymer behavior.

Initial results

In 2014, the DuraStor team's first public reports of its 2010-2013 research indicated that liner and overwrap materials meet or »

SIDE STORY

H_2 storage methods

Hydrogen can be compressed and held under very high pressures, or liquefied and held at cryogenic temperatures. Compression and cryogenic refrigeration increase H_2 energy density per unit of volume, but both are energy-intensive operations, and the vessels for both must be made of materials that can withstand high pressure and prevent hydrogen loss via permeation. The resulting robust containers don't "package" well in commercial trucks, let alone on passenger cars. Further, the cryo option requires continuous energy input to keep hydrogen at -253°C. In the world of ground transportation, it's impractical for any use other than large-scale H_2 storage at vehicle refueling stations.

A third option would be quite welcome in automotive circles. It's technically possible to store hydrogen in a *solid* state at, notably, room temperature and normal atmospheric pressure. The method involves absorption or adsorption of hydrogen into certain metal halides. This method, however, is fraught with challenges and remains commercially impractical.

For the present, auto OEMs are focusing on compressed hydrogen gas, which currently offer the best cost vs. benefit ratio and the fewest practical barriers to implementation.

■ Rotomolded Liner

The DuraStor team designed a rotomolded acetal liner (four liners are pictured, each with gas ingress/egress hardware mounted at the bottom of the vessel) that is compatible with the overwound acetal/carbon fiber tape.

Source | DuraStor Consortium

exceed current performance requirements as long as the liner's nominal wall is ≥5 mm. Post-report work — a recycling study, additional liner molding trials and preliminary overwrap winding trials — has yielded data that will be used by the HOST team to finalize a winding path for the UD tapes. Next, research will focus on producing a monolithic vessel by consolidating the liner and overwrap. Other planned projects include modification of the filament-winding head and development of a drop-in/turnkey robotic manufacturing cell that would enable hybrid vessel manufacturers to adopt DuraStor technology. HOST will follow that with a real-world demonstration project on H_2-powered FCVs to validate both material and process technologies and build a fully capable supply chain.

"Many organizations at the forefront of the hydrogen economy are small innovators with limited budgets," adds Turner. "That's why our robotic manufacturing cell will need to be designed to be adaptable for bespoke and prototype components. We feel confident that it will enable faster development of the hydrogen economy." CW

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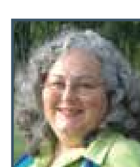
Read this article online | short.compositesworld.com/PVsforFCVs

A list of DuraStor/HOST consortium participants can be found online | short.compositesworld.com/DS-HOST

For a thorough rundown on automaker efforts to build more fuel-efficient, emissions-compliant vehicles, see "Automotive CFRP: The shape of things to come" | short.compositesworld.com/8MhEyKb3

Read more about tank types, their uses and the markets they serve online in "Pressure vessels for alternative fuels, 2014-2023" | short.compositesworld.com/PVOutlook



ABOUT THE AUTHOR

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Exelis Aerostructures: Salt Lake City, Utah

Braided composite shafts and struts for aircraft are its specialty, but there's much more to this Utah, US-based rising star.

By Jeff Sloan / Editor-in-Chief

» A composites manufacturer that supplies parts to the aerospace industry must have, at the least, basic competencies in prepreg-based fabrication processes, including hand layup, automated fiber placement (AFP), automated tape laying (ATL) and autoclave-based cure. A number of composites industry players meet this requirement. But given the great diversity of fiber types and fiber reinforcement forms, resin systems, tooling types and materials and processing technologies available today, and several decades of composites development and application in aircraft of all types, almost every composites supplier of significant size and impact has developed a specialty — an area of expertise that has fueled and sustained the company's growth.

Such is the case with Exelis Aerostructures. Based in Salt Lake City, UT, US, the company easily qualifies on the basics. AS9100C-, ISO14001-, Nadcap-, and Boeing Composite-certified, Exelis excels not only in the autoclaved prepreg arena, but has well-developed expertise in filament winding, resin transfer molding (RTM) and vacuum-assisted RTM (VARTM) as well. That said, Exelis is a standout in the aerospace composites supply chain, today, in large part due to its rich history in carbon fiber braiding, which has helped set this fabricator apart from its competitors.

Same game, new name, growing fame

Although the company's Salt Lake City operations were established decades ago, the Exelis name itself is relatively new, introduced

Exelis CDMC: Future Potential

Exelis Aerostructures operates two facilities in Salt Lake City, UT, US. The newest, the 23,225m² Composite Design & Manufacturing Center (CDMC), was opened in 2012 and includes automated fiber and tape placement activities, hand layup, assembly, filament winding of struts and tubes and fabrication of fuselage frames for the Boeing 787-9.

Billy Mitchell Rd.: 1960s Foundation

The second Salt Lake City facility Exelis operates was established in 1969 and is home of the company's core braiding and filament winding technology. Exelis operates 18 braiders, ranging from 16 to 288 tows. Here, a smaller braider is used to fabricate a tubular preform.

Source (all story photos) / Exelis Aerostructures

in 2011 when Exelis' parent, ITT Corp. (White Plains, NY, US), split itself into three independent companies focused on defense and electronics, fluid technology, and motion-and-flow control. Exelis, with 10,000 employees and US$4.8 billion in revenue, represents the defense-and-electronics segment and is based in McLean, VA, US. The Exelis Aerostructures business operates two Utah facilities, managed by VP/GM Mike Blair.

Although the business is established and sizable, it's neither hide-bound nor immobile. Blair is leading Exelis through an aggressive capacity-and-capabilities expansion, featuring forays into a variety of aerospace applications. Examples abound: Composite floor-beam struts for the Airbus (Toulouse, France) A380, the vertical tail and sponsons for the Sikorsky (Stratford, CT, US) CH-53K helicopter, the upper access covers, blade seal components and outboard wingskins for Lockheed Martin's (Ft. Worth, TX, US) F-35 *Lightning II*, Section 41 and 43 fuselage frames for The Boeing Co.'s (Chicago, IL. US) 787-9 airliner, and the upper shell and other parts for Lockheed Martin Missiles and Fire Control's (Orlando, FL, US) Joint Air-to-Surface Standoff Missile (JASSM).

> Although the business is established and sizable, it's neither hide-bound nor immobile.

Exelis' business development director Jeff Sunderland, however, says the company's expansion, although aggressive, is proceeding methodically and carefully. Enthusiasm is tempered by wisdom won over the long haul. "We are trying to be parochial about going to market," he says. "We want to win work, run it flawlessly and *then* pursue other opportunities. We don't want to bite off more than we can chew — one failure can lead to years of bad reputation."

When *CW* was invited to tour both of the facilities Exelis operates in Salt Lake City in an industrial park due east of the SLC airport, Blair was our guide through the company's original plant on Billy Mitchell Rd., built in 1969, and just a few blocks away, the company's new Composite Design & Manufacturing Center (CDMC) on Amelia Earhart Dr.

Established core, exceptional commitment

The 13,935m² Billy Mitchell Rd. plant is home to many of the legacy technologies with which Exelis has won work and built its business. The bulk of the building's space is consumed by Exelis' braiding operation. Exelis runs 18 braiding machines, some developed in-house. They range in operational complexity from 16 to 288 tows. Manufactured by Herzog (Oldenburg, Germany), the 288-tow braider, also called Stargate, is characterized by Blair as a "solution seeking an application." All of the braided products are processed via RTM or VARTM, with curing done in one of five Grieve (Round Lake, IL, US) ovens located in the braider room. »

In-house Braiding for RTM, VARTM

An Exelis worker monitors activity on one of the company's larger braiders. Exelis is rare among composites fabricators in that it performs most of its own braiding operations. All of the braided product is used in RTM and VARTM processes, followed by oven cure.

High-throughput Winding Hardware

Exelis has used filament winding to build a strong competency in the fabrication of struts, tubes and rods for aerospace applications. Most recently, Exelis established a partnership with Italian machinery firm Bodair to develop a manufacturing cell (shown here) for the high-speed manufacture of struts and tubes. The cell will allow Exelis to quickly customize manufacturing to meet material, diameter, hardware, fitting and boss requirements.

Exelis braids preforms in a variety of sizes — the largest for the fuselage of the JASSM, and the most complex, the variable bleed valves (VBV) for GE Aviation's (Evendale, OH, US) GEnx engine. This carbon fiber/BMI part, also RTM'd, comprises several preforms and features a variety of difficult-to-mold angles and spaces. Exelis makes 11 different VBVs per engine and eventually will produce 12 shipsets per month at full rate production. Another notable braided structure is the flow path spacer for the GEnx engine. The spacer, about 1m in diameter and 60 mm wide, is located aft of the intake fan.

Blair notes that, despite its long history in composites manufacturing, braiding is not usually performed by fabricators. However, braiding is clearly an expertise that Exelis has cultivated carefully and invested in heavily. "Not many companies do their own braiding," Blair points out, but explains, "It gives us more flexibility *and* makes us more lean."

Lessons learned as Exelis developed its braiding expertise are now applied to a variety of processes.

No matter where the Exelis empire expands, it's clear that the company's core strengths are braiding and the products that result. But lessons learned as Exelis developed its braiding expertise are now applied to a variety of processes, including those used to produce its latest product line — struts, tubes and rods (STaR). "We're basically going after galactic domination in struts and rods," Blair quips.

From the braiding room, Blair moved us on to Exelis' filament winding operation, where the process is used primarily to manufacture potable-water and wastewater storage tanks for aircraft. Here, Exelis operates several winders manufactured by Salt Lake City-based Entec Composite Machines Inc. and one system from McClean Anderson (Schofield, WI, US). The tanks, which are about 1m long and 0.25m diameter, are wet wound with carbon fiber/epoxy and are outfitted with a variety of fixtures and attachments, all of which Exelis assembles in house. The wastewater tanks feature stainless steel liners; the potable-water tanks have blowmolded plastic liners. The company manufactures about 700 tanks per year, primarily for Boeing's 737, 747, 757, 767 and 777 aircraft. In addition, Exelis is a certified FAA repair station for the tanks.

CDMC: Seeding the future

If the Exelis Billy Mitchell Rd. facility represents the company's legacy processes and applications, then the CDMC site on Amelia Earhart Dr. represents its potential. This new (2012) 22,760m^2 purpose-built plant houses the equipment and facilities necessary to meet all of the contemporary requirements of aerospace composites manufacturing — high-precision fiber and tape placement, cleanroom layup, large-format autoclave cure, precision machining, nondestructive inspection (NDI) and assembly. Most

Emphasis on AFP Capabilities

Exelis is emphasizing in the CDMC its ability to meet automated fiber placement (AFP) application requirements. Here, a Fives Cincinnati (formerly MAG, Hebron, KY, US) VIPER AFP unit lays down prepreg for a carbon fiber laminate.

Exelis "Struts" Its Stuff

Struts like this one are manufactured by Exelis for the Airbus A380 main floor support system. Exelis manufactures 95 struts per shipset for the aircraft.

of all, the facility features space, and plenty of it, to accommodate fabrication of very large parts. And within that spacious environment, says Blair, Exelis has the room to invest in new equipment and develop the additional expertise that the aerospace industry might demand. "You have to build it and they will come," Blair asserts. "If you want to do automated fiber placement, you need to invest — invest in capability, machines and people."

At the heart of this investment are two large machines. The first is a dual-station Fives Cincinnati (Hebron, KY, US) VIPER AFP machine, capable of laying down up to 32 tows of 3.2-mm carbon fiber. At the time of *CW's* visit, Exelis was using this machine to demonstrate the capability to mold the upper wingskin of the F-35 *Lightning II*. Exelis hopes that it will win work fabricating this structure. The second machine is a Fives dual-station, gantry-style automated contour tape layer, with an 18.3 by 4.9 by 1.2m build envelope and the capacity to place 76-, 152- or 305-mm wide tape (top photo, p. 32). This machine is being used to demonstrate Exelis' flat-panel manufacturing capability for a number of aircraft components, including horizontal and vertical tail structures.

People-powered production

Adjacent to the fiber- and tape-placement space is Exelis' 1,850m^2 cleanroom, where technicians focus on hand layup of F-35 access covers, blade seals and wingskins, CH-53K sponsons and tails (vertical and horizontal), and S-76 helicopter rotor blades and flex beams. The room features four tool prep bays that each feed one of four production lines (cutting tables), with 12 workstations on each line. Prepreg is supplied from three freezers that line the cleanroom's back wall, and finished layups are transferred immediately to autoclaves located in an adjacent space. The work in the cleanroom is team-based, and Exelis has given employees in this area some ownership: "The people working closest to the product are the smartest about that product," contends Darin Friess, director of engineering. For that reason, they are given a measure of authority and operate with a degree of autonomy. "They've developed their own kanban and troubleshooting," he says, adding, "They are always looking for ideas to continuously improve."

Exelis operates six autoclaves in Salt Lake City — four from ASC Process Systems (Valencia, CA, US), one from Taricco Corp. (Long Beach, CA, US) and one from American Autoclave (Jasper, GA, US). They range in size from 0.9 by 1.5m to 4.6 by 15.2m. »

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Tight-tolerance Tape Laying

The second largest machine in the CDMC is a Fives Cincinnati dual-station, gantry-style automated contour tape layer, with 18.3 by 4.9 by 1.2m build envelope and capacity for tape 76, 152 or 305 mm wide. The entire CDMC is organized to accommodate large-part, autoclave-based fabrication of tight-tolerance aerospace structures.

Part Inspection a Priority

Exelis operates 10 nondestructive inspection (NDI) workstations in its Salt Lake City facilities. NDI technologies include pulse-echo, through-transmission, hand-scan and bond-scan systems.

CDMC: All-autoclave-cured Production

Although Exelis' braided products are used primarily in out-of-autoclave (OOA) processes, all of the fabrication in the CDMC is done with autoclave cure. The company operates six autoclaves, ranging in length from 1.5 to 15.2m.

After cure, most parts are transferred to the machining shop for drilling, trimming, routing and cutting. Exelis operates eight 5-axis machining centers, including seven from Breton SpA (Castello di Godega, Italy) and one from Komo Machine Inc. (Lakewood, NJ, US), but most of the work done in this building runs on two Breton 1300 units, the facility's most flexible CNC centers. Exelis, says Friess, favors cutting tools supplied by Precorp (Spanish Fork, UT, US), but has been testing other cutters, including one from LMT Onsrud LP (Waukegan, IL, US) that has fared well.

Nondestructive inspection is done at 10 work centers, ranging from single- to 5-axis capability, using methods that include pulse echo, through-transmission, hand-scan and bond-scan.

One of the largest spaces at the CDMC facility is devoted to the assembly of a variety of structures for which the rest of the facility makes component parts. These include the vertical and horizontal tails and the sponsons for the CH-53K, for which Exelis fabricates a total of 193 different composite parts, made with prepreg supplied by Hexcel (Stamford, CT, US). Exelis has already manufactured seven shipsets of parts for Sikorsky, for the helicopter's system design and development phase. This will be followed by four more shipsets that will be used as test articles. This work, assuming positive test results, could be followed by contracts for low-rate production and, perhaps, rate production of up to two shipsets a month by 2021.

Struts and tubes: STaR power

One of the newest operations at the CDMC harkens back to the Exelis' filament winding legacy. The company has licensed technology from Bodair SA (Oupeye, Belgium) for Exelis' STaR (struts, tubes and rods) product line. Exelis plans to use Bodair's manufacturing cell, which encompasses filament winding equipment, curing technology, machining, drilling, NDI, painting, priming and bushing installation, to produce a variety of floor beam and wingbox struts, control rods and torque tubes for aircraft. Notably, STaR enables easy reconfiguration of fittings and bushings to meet customer and application requirements. "The combination of the unique manufacturing process and automation technology positions us to meet the market demands, with the ability to produce upward of 40,000 STaR parts per year," Blair adds. STaR's production flexibility and potential unit output helped Exelis land one of its largest programs to date — manufacturing the main deck floor beam struts for the Airbus A380 aircraft. Exelis makes 95 A380 struts per shipset and will manufacture 240 struts per month at rate production.

Plugging into potential ventures

Our final stop in the CDMC revealed a new Exelis venture that has nothing to do with aerospace, but demands all of the performance hallmarks of the company's other work. The product, called the Bear Claw, is a filament wound "plug" used during drilling in oil and gas production (see "Learn More," p. 31). Sized from 114 to 140 mm in diameter, Bear Claws measure about 0.75m in length. The plugs are assembled at Exelis up to a certain point, beyond which they can be customized easily to meet customers' different end-use requirements. Exelis currently makes 1,100-plus plugs per month and delivered more than 12,000 in 2014. "It's a high-temperature, high-pressure, pretty demanding environment," Blair says. "It's not aerospace, but it's *like* aerospace."

Bear Claws are a harbinger of ventures yet to come. In fact, if known growth opportunities at Exelis come to fruition as planned, the company expects to add another 13,000m^2 to the CDMC in 2015.

The activities and expansion at Exelis Aerostructures' Salt Lake City location are attracting attention from not only new customers but also other OEMs within the aerostructures community, including Boeing, Northrop Grumman (Palmdale, CA, US) and Spirit AeroSystems (Wichita, KS, US). "A lot of us look at this as a chance to build a legacy," Blair notes, but adds that despite the serious challenges inherent to the advanced composites territory, "It's a lot of fun." CW

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CFRP camera boom enables safe spill inspection

NONA Composites' 32m REACH structure meets tight remediation schedule at DoE radioactive waste storage site.

By Ginger Gardiner / Senior Editor

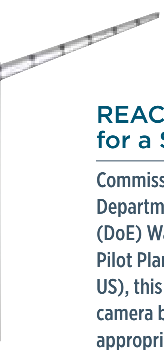
» Opened in 1999, 42 km southeast of Carlsbad, NM, US, the US Department of Energy's (DoE) Waste Isolation Pilot Plant (WIPP) stores clothing, tools, equipment, soils and other materials contaminated by man-made radioactive elements that have been removed from 22 defense-related environmental clean-up sites to date. Kept in disposal rooms carved out of a 762m-thick salt deposit 655m below the earth's surface, most of the waste (96%) can be contact-handled (CH) by personnel, does not require additional shielding and is stacked in columns within the underground storage cells. The remaining 4% is deposited in chambers bored into the cell walls, requires shielding and is remotely handled (RH) waste — that is, robots and other machinery are used to transport it (see top photo on p. 35). When a 55-gal drum of CH waste burst in February 2014, a small quantity of radioactive material was released to the surface through the WIPP's ventilation system. No one was injured, and when all WIPP workers were tested for radiation, none showed exposure levels higher than that of a typical medical X-ray. Nevertheless, the next step was a full investigation of the accident to determine the extent of the damage in the storage room in an effort to re-establish optimal operational safety.

WIPP requested quotes for a steel support structure and cantilevered 27m beam that could deploy a 7-kg sensor package. The system, called REACH, would have to be delivered in pieces that could be assembled underground. Further, the beam would have to be maneuverable, laterally and vertically, around waste containers to facilitate remote video assessment *without* disturbing post-eruption radioactive particulate that had settled on storage-area surfaces.

Cornerstone Research Group (CRG, Dayton, Ohio) and two Dayton-based subsidiaries, NONA Composites and Advantic LLC, were awarded the beam and sensor package contract on July 21. The REACH system, however, was to be installed and in use *before* the end of September. Less 10 days for shipping to the WIPP site, that gave the CRG team only *eight weeks* for design, tooling, fabrication, assembly *and* shakedown testing.

The design and structural engineering was roughed out by Advantic, a CRG spin-off that specializes in advanced composite solutions for the construction and infrastructure markets. "The camera boom had to have a 27m clear reach, but there was also a vertical requirement, in that the boom had only 0.8m of operable space between the ceiling and the top of the waste stack," explains Advantic VP of engineering Brad Doudican. Therefore, the design was stiffness-driven due to the limited allowable deflection. It also needed to be as light as possible to facilitate mobility and full extension. "We ended up with a box-beam that changes depth continuously along its length," says Doudican. The width was constant at 152 mm but depth declined from 762 mm at the support to 203 mm at the tip. C-channels would comprise its top and bottom caps, and flat plates would form the sidewalls.

The beam was broken down into 12 sections, each 3m long, to make it man-portable and easy to transport via elevator before assembly underground. Section connections would have to be easy to align and attach because assembly would be completed in a high-temperature environment by technicians in full-body protection suits, wearing three layers of gloves.



REACHing for a Solution

Commissioned for the US Department of Energy's (DoE) Waste Isolation Pilot Plant (Carlsbad, NM, US), this very long 32m camera boom for the DoE's appropriately named REACH project was designed for and built with carbon fiber composites, and then tested in only seven weeks, enabled by No Oven, No Autoclave (NONA) technology developed by the Dayton, OH-based NONA Composites team (pictured here with the finished beam). The beam was light enough to be cantilevered from a steel support mounted to the pictured mobile frame.

Source | NONA Composites

Design for *rapid* molding

"Design for manufacturability was our greatest challenge, because we needed to move so quickly," recalls NONA Composites president Ben Dietsch. "We also sought the greatest flexibility downstream to give us room to refine the structure if needed. This was important because we had to start without a full analysis completed." This approach permitted the team to initiate the first stages of manufacturing before the structural analyses were in hand.

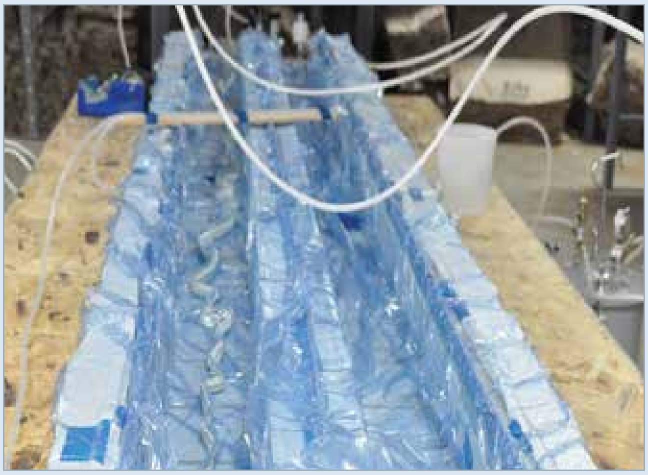
The big push in the first week was materials selection. "We were limited in what materials we could use because they had to be commercial, off-the-shelf — specifically, available to go on the truck on the afternoon we got the contract," quips Doudican. This also impacted design. For example, IM7 (from Hexcel, Stamford, CT, US) was not an option for the carbon fiber (CF) because the lead times were too long. "So we started with »

Close Up, But from a Distance

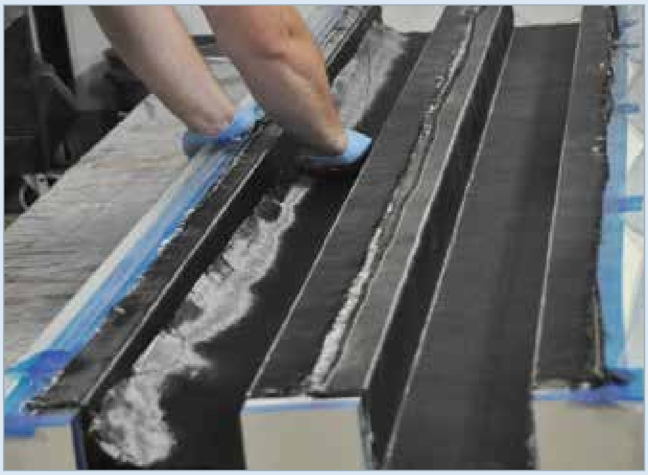
REACH was built to enable workers in protection suits (bottom photo) to remotely inspect — via a video camera package mounted on the composite beam — a burst 55-gal drum of contact-handled waste (middle photo) without disturbing the radioactive dust that covered its storage room (like the one pictured in top photo).

Source | WIPP, US DoE

1 Tooling for beam sections was machined from high-temperature polyurethane foam backed by wood substructures. All 14 tools for the beam sections were completed in one week.



3 A second team, working in parallel with the layup crew, bagged and infused completed layups for as many as four parts at one time. C-channels (shown here) and sidewall plates were infused with NONA RT-177 epoxy resin in 35-40 minutes. Overlapping Steps 2 and 3 saved significant time in processing.



2 Beam manufacturing required two teams working simultaneously. The first performed layup of dry reinforcements. The shear-driven side plates used a 12K 2x2 twill carbon fabric while C-channels featured 24K unidirectional reinforcements. Both used plain-weave carbon fiber fabric on outer surfaces.

4 Here, infused parts cure inside insulated boxes, custom-built from readily available hardware-store foam and fiberglass insulation, to contain the heat generated during resin exotherm. The NONA-developed epoxy infusion resin reached peak exotherm in about two hours and required no additional heat source. Cool-down took another four hours. All laminated parts were completed in two weeks.

a rudimentary design using standard-modulus CF to see if it would even work," says Doudican.

Because the two weeks prior to getting the contract had been spent analyzing all available off-the-shelf tooling and fabrication materials options, the team was able to place orders on day one with suppliers Composites One (Arlington Heights, IL, US) and North American Composites (Hampton, NH, US). "We ended up with a mix of plain-weave carbon fabric, a 12K 2x2 twill and a 24K 630-g/m^2 unidirectional broadgood — all standard modulus," he says.

Doudican explains the unis were used on the box beam's top and bottom, formed by the 6-mm thick C-channels, while the 2-mm thick side plates were shear-driven, and so used the 12K twill. He notes, "All of the parts used plain weave on the outer surfaces to enable good bonded joints and finish coating. Unfortunately, we had to paint it with intumescent paint, so you couldn't see the carbon fiber surfaces."

For the resin, the team chose its own No Oven, No Autoclave (NONA) RT-177 two-part epoxy, says Dietsch, "because we had a

5 Demolded parts (C-channels are shown at right) needed trimming before assembly. Flat panels (inset) were outsourced for waterjet cutting to save time.

7 Each bonded assembly was then drilled and riveted to produce a bonded/bolted box beam section (left). A special assembly jig (right) then mated adjacent sections to ensure precise alignment for machining of the holes that would enable workers to bolt sections into the final beam structure.

6 Flat plates and C-channels were bonded together, using this custom-built jig and an acrylic adhesive filled with glass microbeads that helped maintain a consistent bondline thickness during assembly.

8 On week six, the 12 box beam sections were mated and bolted together for the first time. Subsequently, the beam was disassembled and reassembled before each test use, as part of the shakedown trials performed prior to shipment of the REACH system to the WIPP site.

Source (all step photos) | NONA Composites

good knowledge of its processing and it afforded us the short cycle time and fast tooling we needed." NONA Composites, in fact, was formed by CRG to commercialize it. Matured through NASA-funded SBIR Phase I and II large-structure, carbon fiber-reinforced plastic (CFRP) tooling programs, the resin enables production of tooling and parts with operating temperatures of 204°C and 177°C, respectively, with no heat source beyond the resin's exotherm during cure. "We did evaluate other systems," he notes, "but the NONA cure cycle was so fast, we didn't even have to rely on an oven."

While NONA Composites initiated its tooling and beam manufacturing processes, CRG and Advantic finished a variety of structural analyses, using Dassault Systèmes' (Velizy-Villacoublay, France) Abaqus finite element analysis (FEA) suite and CATIA for solid modeling. Composite laminate properties were modeled in Helius:CompositePro, which is now Autodesk (San Rafael, CA, US) Simulation Composite Design 2014. "We did a lot of testing to validate the design," says Dietsch. "This was part of the quality-control process we developed and documented as part of the

»

Camera and Beam, Ready for Action

The completed REACH system was deployed and tested six times by week seven, including tests of the camera transport rover (inset). It was then transported to WIPP, assembled and used for training before deployment in following months.

contract. We did trial panels for laminates, bonded sections and also sections which were bonded and riveted to validate the final assembled structure."

Fast foam tools, oven-less cure

Because NONA's epoxy infusion resin requires neither autoclave nor oven curing, low-cost tooling (see Step 1, p. 36) could be machined from high-temperature polyurethane foam supplied by General Plastics Mfg. Co. (Tacoma, WA, US). Two foam grades, FR 4718 and FR 4518, were used because there wasn't enough of either in stock to meet the project's total need.

NONA used tools of two types: Two 152 mm wide by 3m long C-channel tools and 1m wide by 3m long flat tools for the progressively smaller side plates, all supported by plywood substructures. "Everything was on wheels for ease of transport and work flow," notes Dietsch. "We would do layup in one area and then move the tool to the infusion and cure area, some 20 to 30 yards away." Fabrication of all 14 tools took slightly more than seven days. To save time, each tool was integrated into production as soon as it was finished.

"We could infuse up to four parts at one time, so one team was laying up C-channels and side plates while another was infusing," Dietsch details. "We infused most of the parts within 35 to 40 minutes. We typically double-bag for a backup to ensure vacuum integrity and reduce the risk of losing the part." After parts were infused, they were rolled to the cure area while still in the tools and under vacuum. "We kept each part under vacuum in the second bag during the whole cure."

Insulation boxes, made from hardware-store rigid foam insulation board and fiberglass insulation, were then lowered over each tool to contain the heat generated during exotherm (Step 4, p. 36). "We already knew what insulation we needed to reach the temperatures required for full cure," explains Dietsch. "It only took us a half day to build all of the insulated boxes. We couldn't have found an oven big enough to cure the parts in the time we had, nor did we have time for a long oven cure cycle."

As part of the cure regime and quality control (QC) process, part temperatures were monitored by thermocouples installed across the part. All parts had to meet a minimum temperature requirement yet remain under a maximum allowable peak temperature, but Dietsch claims that the resin chemistry's design is such that "you don't need the temperature-control software used with traditional epoxy processing." The user can determine when the peak exotherm will occur based on the part thickness and type of tooling used. "You don't have to adjust any catalysts or accelerators," he points out.

For this project, the laminates reached peak temperature within two hours, followed by a cool-down period of four hours. Despite the resin predictability and the simplicity of the insulation-box technique, Dietsch concedes, "We could still have had issues with temperature consistency across the part. But the past five years have helped us to understand the heat and energy balance." The team, therefore, achieved a part yield of more than 90% (less than 10% scrap) over the whole project and recorded the fastest timeline, to date, for NONA Composites-built parts.

Ensuring accurate assembly

All of the composite parts were laminated within a couple of weeks. It took roughly two more weeks for postmold processing of the demolded parts and then assembly of the box beam sections (Step 5, p. 37). Trimming and machining were partly done in-house and partly subcontracted. "Waterjet cutting of the flat panels was so much faster than machining in-house," Dietsch recalls. "We could do one run per day for a couple of days and it was all done." The channel trimming, however, took more setup. So, the team did that in-house using custom-built jigs.

The C-channel and side-plate surfaces were then prepared for bonding. Lord Corp.'s (Cary, NC, US) 7545 acrylic adhesive was filled with glass microbeads to help maintain a constant bondline thickness. "We chose this because it had a short setup time — specifically, within a couple of hours vs. 24 hours for other systems," recalls Dietsch. "We couldn't handle that much delay in the overall timeline."

The completed box beam sections were assembled using a joint system that incorporated steel connection plates and high-tolerance shear pins and rivets, for which holes had to be machined (Step 6, p. 37). "We had to create a fairly complicated assembly jig that could mate two bonded beam sections simultaneously in order to make sure each »

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section was aligned perfectly," Doudican explains (Step 7, p. 37). "We could not afford a few inches of vertical deflection in the final assembled beam due to loose assembly tolerances."

After bonding, dry fitting and machining of holes in the custom jigs, the nine box-beam sections were mechanically fastened to form the 32m structure (Step 8, p. 37).

By week six, the REACH system had been assembled and tested. "This dry run had to be completed before anything could be shipped," says Dietsch.

While the CFRP beam was in progress, a parallel effort was mounted to design the system that would move the assembled beam and a small *Mars Rover*-type sensor caddy that would transport a camera and sensors along the beam, including the electronics and control software. A composite beam cradle and support frame was designed and fabricated using pultruded Extren Shapes from Strongwell Composites (Bristol, VA, US). Testing of these systems together with the beam was completed with one week to spare.

"So the project took seven weeks total," says CRG CEO Patrick Hood, "but two of those were final testing and system shake-down. The system was deployed at least six times, with less than 1 mm deflection at the support side. We utilized actuated tilt devices within the support structure, which allowed us to be well within our 762-mm deflection limit under load." Doudican points out that some of the observed deflection was caused not by changes in the composite beam, but rather by thermal expansion of the steel in the lateral motion system during daily temperature cycles.

The beam was assembled and deployed for training at WIPP in September and was used to survey the potentially contaminated areas during the next few months.

Planning pays off

"We're very proud of what our team accomplished in such a short span of time," says Dietsch. "This was a highly orchestrated dance between structural, mechanical and electrical design, procurement, fabrication and validation accomplished in a highly integrated process — all happening simultaneously." Its success, he says, was in large part due to the energy and effort spent in planning, but adds, "The speed and ease of using NONA afforded us a great deal of that time." CW

ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and has accrued more than 20 years in the composites industry.
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Composites Events

Feb. 3-5, 2015 — Palm Springs, CA, US
SPE Thermoset Conference (TOPCON)
www.spethermosets.org

Feb. 18-19, 2015 — Los Angeles, CA, US
Test Methods for Composite Materials
www.seminarsforengineers.com/seminars/Test-Methods-for-Composite-Materials.php

Feb. 24-27, 2015 — Geelong, VIC, Australia
2015 Carbon Fibre – Future Directions Conference
www.vcamm.com.au/events/cf-fd-conference-2015

Feb. 25-27, 2015 — Moscow, Russia
COMPOSITE-EXPO-2015
www.mirexpo.ru

March 2-4, 2015 — Beverly Hills, CA, US
SpeedNews 29th Annual Commercial Aviation Industry Suppliers Conference
http://speednews.com/commercial-aviation-industry-suppliers-conference/registration

March 9, 2015 — Paris, France
SAMPE Europe Summit
www.sampe-europe.org

March 10-12, 2015 — Paris, France
JEC Europe 2015
www.jeccomposites.com

March 15-19, 2015 — Dallas, TX, US
NACE Corrosion 2015
http://events.nace.org/conferences/c2015/index.asp

April 13-15, 2015 — Cologne, Germany
8th International Conference on Bio-Based Materials
www.biowerkstoff-kongress.de

May 4-7, 2015 — Atlanta, GA, US
AUVSI Unmanned Systems 2015
www.auvsi.org/events

May 14-16, 2015 — Atlanta, GA, US
Composites Pavilion – American Institute of Architects Convention 2015
http://Convention.aia.org/event/homepage.aspx

May 18-21, 2015 — Baltimore, MD, US
SAMPE Baltimore Conference and Exhibition
www.sampe.org (click "events")

May 18-21, 2015 — Orlando, FL, US
WINDPOWER 2015
www.windpowerexpo.org/wp15

June 2-4, 2015 — Houston, TX, US
JEC Americas/Techtextil North America/Texprocess Americas
www.jeccomposites.com/events/jec-americas-2015-houston

June 16-17, 2015 — Stade, Gemany
9th International CFK-Valley Stade Convention
www.cfk-convention.com

July 12-18, 2015 — Chengdu, China
ICCE-23, 23rd Annual Int'l Conference on Composites and Nano Engineering
www.icce-nano.org

July 19-24, 2015 — Copenhagen, Denmark
ICCM20 – 20th Int'l Conference on Composite Materials
www.iccm20.org

Aug. 17-20, 2015 — Edmonton, AB, Canada
CANCOM 2015
cancom2015.org

Sept. 8-10, 2015 — Novi, MI, US
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SAMPE Europe Conference 2015
www.sampe-europe.org

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

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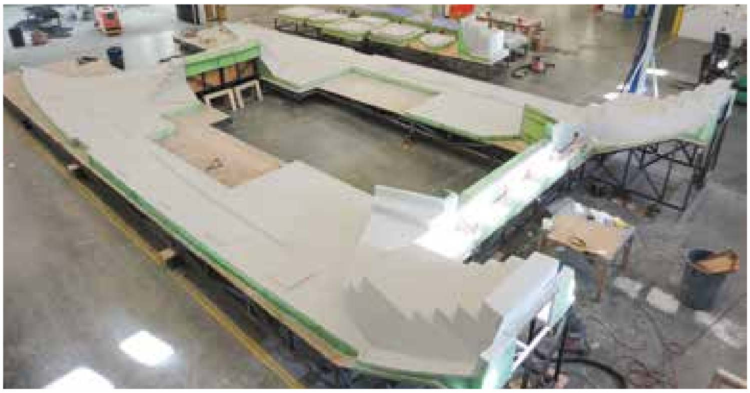
MOLDMAKER BYPASSES PATTERNS FOR HIGH-TECH PRODUCTION CATAMARANS

Direct-to-milled-tool process simplifies large deck mold development.

Gunboat International's *78* catamaran features a one-piece deck, molded from composites. Pictured is the smaller Gunboat *60* of similar design. Source / mouldCAM



Gunboat's mold was built up by mouldCAM from EPS foam, over which is placed a single layer of fiberglass laminate and overlapping ribbons of tooling paste. Paste deposition is in progress (bottom left and right). The photo above shows the machined, assembled mold. It was disassembled for shipment to Gunboat's facility. Source (all photos) / mouldCAM

Cruising catamaran builder Gunboat International (Wanchese, NC, US) is well known for its high-performance, ocean-going vessels, ranging in length from 17 to 27m, that make use of raceboat technology while delivering comfortable customer amenities. The company's all-carbon-fiber sandwich design, and a production strategy that infuses hulls and connecting bridge as one part — no joints — greatly reduces hull weight while delivering high stiffness.

Gunboat's designs require complex, multi-part tools, which are provided by tooling specialist **mouldCAM** (Bristol, RI, US). "We are going 'direct to milled tool' and avoiding the step of building patterns," says Gunboat founder Peter Johnstone. Jason Cilio, mouldCAM's program manager, explains the process: "We start with the three-dimensional CAD surfaces, and produce a CNC cutting file."

For the large mold used to produce a one-piece deck for the Gunboat *78* catamaran (pictured at left), mouldCAM's 5-axis CNC milling machine, supplied by **CMS North America Inc.** (Caledonia, MI, US) is used to rough-cut the approximate mold shape from expanded polystyrene (EPS) foam blocks, to create a geometry that is slightly smaller in profile than the final part. Then, a single ply of fiberglass/epoxy laminate is applied to the machined EPS. The double-bias (±45°) fiberglass is often supplied by **SAERTEX USA LLC** (Huntersville, NC, US), and is wet out with epoxy resins from either **Pro-Set Inc.** (Bay City, MI, US) or **Axson US Inc.** (Madison Heights, MI, US), depending on the engineering requirements.

Then, explains Cilio, a worker applies seamless epoxy modeling paste, supplied by Axson, over the cured laminate, at a thickness of ~15 mm. The paste is applied in overlapping ribbons and cures at room temperature. The resulting shape is slightly larger than the finished mold, and is then "finish-machined" to achieve final part shape, with <1 mm tolerance.

A Duratec mold coating from **Hawkeye Industries Inc.** (Bloomington, CA, US) is applied to the final machined surface, which is supported by a steel/plywood frame to ensure its stiffness. The *78* deck mold was built in four sections, each built separately, to allow for shipment by truck to Gunboat. The mold surfaces have registration features and flanges that enable assembly at the Gunboat facility prior to deck production, says Cilio.

"We offer a robust direct-to-mold process that provides dimensionally accurate parts, for a relatively low cost investment," asserts Cilio. The process eliminates the need for an intermediate splash or pattern, which saves considerable time and labor.

Cilio does caution that the EPS foam must be handled with care to avoid exposure to excessive heat, and mold releases must be carefully selected to avoid the risk of damage during part demolding. CW

Product Showcase

» MACHINING SYSTEMS

Large-format waterjet cutters

OMAX Corp. (Kent, WA, US) has expanded its line of MAXIEM JetMachining waterjet machining centers. The first five models in this "next-generation" product line were introduced to meet customer demands for cost-efficient, high-performance waterjet cutting technology capable of greater productivity. The lineup now comprises eight models, including the new 2060, 2080, and 3060 JetMachining Centers. Designed to machine parts up to 2m wide, the 2060 and 2080 can handle lengths of 6.25m and 8.3m, respectively. The 3060 JetMachining Center boasts a wider work envelope, for the machining of a wide range of materials and thicknesses, from metals and composites to glass and plastics. This machine features y-axis cutting travel of 3.1m.

Onboard each machine is OMAX's Intelli-TRAX linear drive system, which features brushless servomotors, integrated servodrives and high-precision linear encoders that provide constant and continuous feedback on the actual position of the cutting head. The result is faster, smoother motion with increased part-cutting accuracy. The all-in-one Windows 8 controllers come pre-loaded with the OMAX Intelli-MAX Software Suite, which reportedly eases generation of complex geometries. **www.omax.com**

» TEST EQUIPMENT

Video extensometer

Instron (Norwood, MA, US) has introduced a new video extensometer, the AVE 2. It conforms to testing standards ISO 527, ASTM D 3039 and ASTM D 638. The second-generation unit is described as a fully integrated device that adapts to the normal fluctuations of environmental conditions in the lab and can be adapted to any testing machine on the market that uses a ±10V analog input (performance depends on the system). Designed to reduce errors from thermal and lighting variations that are common in most labs, the AVE 2 uses a real-time 490-Hz data rate with ±1μ accuracy. The AVE 2 measures the modulus and the strain-to-failure of almost any material, including composites, plastics, metals, textiles, films, bio-materials and more. **www.instron.com**

» MOLD PREPARATION

Water-based, semi-permanent release

Chem-Trend (Howell, MI, US) has launched Zyvax TakeOff, a new water-based, semi-permanent release agent formulated for aerospace manufacturers that use vacuum-bagging and autoclave-curing technologies to fabricate parts from carbon fiber/epoxy prepreg. TakeOff does not require a sealer, in most cases, when used on high-quality mold surfaces. Applied to molds by wiping or spraying, the release can be used on tools of varying temperatures, thus reducing the required downtime to allow the mold to cool, as is sometimes necessary when using solvent-based release agents. Additionally, Chem-Trend says there is minimal transfer of the release agent to the molded part. That reportedly eliminates or significantly reduces the need for cleaning the demolded part prior to a post-mold processing (e.g., painting and bonding) that requires optimum adhesion. For parts that do require cleaning, a mild detergent and water will remove transferred release agent. **www.chemtrend.com**

» SOFTWARE

Enhanced fatigue analysis

MSC Software Corp. (Newport Beach, CA, US) has released MSC Nastran 2014 and Patran 2014. Nastran 2014 provides enhancements to its solver-embedded fatigue functionality as well as improvements in performance and ease of use. These include upgrades to the external super-element (SE) capability to provide users with the ability to rotate, move or mirror a primary external SE; new capability to activate and deactivate rigid elements in subcases and improve flexibility; multiaxial assessment for insight into validity of standard stress-life or strain-life fatigue analysis; and support for the industry-standard remote parameter control (RPC) files. Patran 2014 supports the new fatigue analysis capabilities, delivers improvements to nonlinear analysis support and provides support for the new capabilities of MSC Nastran and MSC Fatigue. Its CAD import/export capability has been significantly improved to support recent CAD systems and is 25% faster. The GUI drives the new MSC Nastran Embedded Fatigue capabilities. As model size increases to ensure greater fidelity of the model, Patran 2014 has been enhanced to provide faster visualization. **www.mscsoftware.com**

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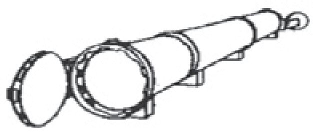

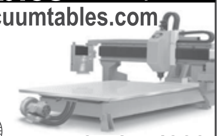

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ADVERTISING INDEX

A&P Technology Inc. . . . . Inside Front Cover

Amamco Tool. 39

C.R. Onsrud Inc.. . . . . .Back Cover

CGTech 26

Composites One LLC 40

Coastal 41

Fives Cincinnati 27

Interplastic Corp. 7

Janicki Indsutries 15

JEC 17

McClean Anderson 2

Miller-Stephenson Chemical Co. Inc.. .7

Norplex Micarta. 3

North Coast Composites. 19

Pro-Set Inc. 11

RevChem Plastics Inc. 15

SGS Tool Co. 33

Society of the Plastics Industry/NPE 2015 23

Superior Tool Service Inc. 16

Torr Technologies, Inc.. 2

Wisconsin Oven Corp. . . . . Inside Back Cover

Wyoming Test Fixtures Inc.. 38

SHOWCASE

Managing weight in emergency medical transport

Repetitive-strain risk for first responders sends emergency equipment provider back to the drawing board to develop more ergonomic cot.

By **Jeff Sloan** / Editor-in-Chief

» Emergency medical technicians (EMTs) help people who are injured, severely ill or otherwise in need of emergency medical care, but also put themselves at risk via contact with diseased or potentially physically violent patients and exposure to injury associated with fire, explosive devices and traffic around vehicular accidents. Often overlooked, however, is back injury — well known in the profession, but little known outside of it — from repetitive lifting. EMTs bear the weight of both the patient and the stretcher (EMTs call it a *cot*) as the cot's legs are retracted and the patient is moved into or out of an ambulance.

Stronger, more flexible cot design

When EMS OEM Ferno Composites (Wilmington, OH, US) recognized a need in the patient transport market for a cot system that would minimize weight-bearing by EMTs who face the risk of repetitive-stress back injuries that can shorten a first responder's career, it introduced the iN∫X, with independently operated composite front and back legs.

Source / Ferno

For years, ambulance cots have featured manually operated, adjustable-height platforms, which enable EMTs to load patients onto cots at or near the elevation of floor, chair, bed or car seat on which they find them. When the patient is securely onboard, the cot is typically raised by the EMTs, manually, to full height and then wheeled to the ambulance. Critically, most of the energy of lifting and lowering is provided by the EMTs, as the cot's legs are extended or collapsed.

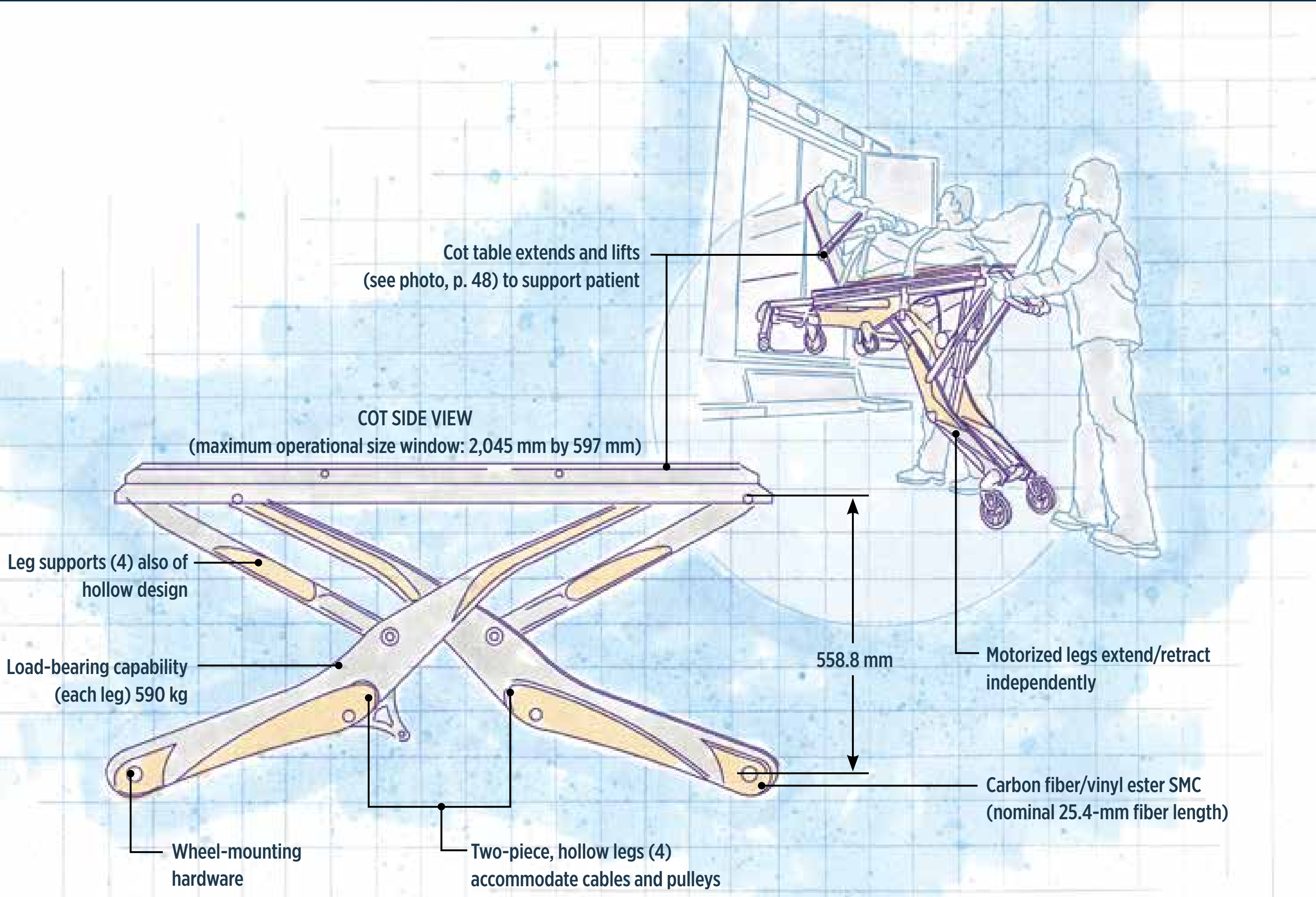
Cot manufacturers eventually developed motorized units that take the manual labor out of leg extension and contraction. One motorized solution came from emergency medical services (EMS) equipment supplier Ferno (Wilmington, OH, US), but the company recognized that the weight management issue was more complex. Most conventional ambulance cots in the US feature aluminum tube construction and rely on two hinged, X-style support legs that are connected to its four wheels via a rectangular frame at the ends of the legs. Because they are interlocked, the four legs and all four wheels move *in concert*. Getting the patient up stairs, over curbs, across grassy ground, muddy roads or other variable terrain and around highway barriers to the ambulance in relative comfort and safety often requires that EMTs either partially or fully collapse the leg structure (motorized or not) and then bear the full weight of the patient to keep the cot stable. Years of repetitive weight-bearing can lead to chronic and debilitating back injury for an EMT, potentially cutting short his or her career.

Motorized, *de-coupled* legs

To solve the problem, Ferno began development work on what would become the iN∫X (pronounced "in-ex"), the world's first EMS cot that features two pairs of motorized, *independently* operated legs. With the touch of a button, EMTs can raise or lower the front or back legs, as needed, and can keep one leg set deployed, in most cases, to help support patient weight as they negotiate stairs and other challenges.

Tim Wells, global emergency product manager at Ferno, says the company conceived of the iN∫X five years ago and then, through a series of focus groups, fine-tuned the design and confirmed that it was on the right track. Initial reaction to the design, Wells says, was overwhelmingly positive.

"EMTs and fire personnel looked at the iN∫X and could see right away the advantage," says Wells. "This is a love-affair career, and EMTs have a real passion for what they do.



DESIGN RESULTS | **Ferno Composites' iN∫X Ambulance Cot**

- EMT weight-bearing during patient transport is minimized by making each motorized leg set on the cot independently operable.
- A two-piece, hollow design allows the legs to accommodate internally the cables and pulleys used in leg extension and retraction.
- The SMC wall thickness in each leg is optimized to meet a stringent weight-bearing requirement yet minimize the weight penalty in leg fabrication.

Illustration / Karl Reque

Anything that allows them to do their job longer — as iN∫X does — is welcome."

Lose weight, please

To make the iN∫X vision come to life, however, was another matter. Ferno project engineer Nick Valentino says Ferno's experience was primarily with aluminum, but its engineers soon learned they'd have to change their thinking about not only leg design but materials as well. For the latter, Ferno turned to one of its suppliers, Citadel Plastics (formerly Premix, North Kingsville, OH, US). Called in early, during product development, Citadel representatives thought that the application was better suited for composites. Ferno's experience with composites, however, was limited. "It was a new material for us, so we really had to put it through its paces," Valentino says. "But we're really just trying to keep weight down and this [composites] allowed a form and look that we wanted, and it created a part that got rid of a lot of other parts." Citadel was retained to help guide design and engineering decisions.

The resulting leg design clearly offers aesthetic appeal (see photo, p. 46), but Valentino says that once the decision to use composites had been made, function took precedence. The challenge, he says, is that all EMS cots must conform to some basic size and shape standards for ambulance compatibility. In addition, a cot must fit into standard-sized elevators and pass through standard-sized doorways. That meant Ferno was confined, with the iN∫X, to a fixed shape envelope of 597 mm wide and 2,045 mm long. Therefore, the independently operated legs, when both are closed, must fit within the shape envelope without interfering with each other, and allow sufficient room for mounting actuator motors between each set of legs without interfering with other cot functions.

"Leg geometry is more function than form," Valentino notes. "They [the legs] must fit into an envelope that is typical of current designs. The legs must pass through each other, past actuator mounts and clear all bumpers."

Roy Bendickson, product development engineer at Citadel, worked closely with Valentino and Ferno on leg design and »

Ambulatory & Adaptable

Ferno worked with Citadel Plastics (North Kingsville, OH, US) to develop the carbon fiber/SMC legs, which feature a two-piece shell design that accommodates cables and pulleys for leg extension and retraction. Each leg on the iN∫X is designed for a load of up to 590 kg, which is twice the overall load rating of the entire cot.

Source / Ferno

helped guide material decisions to enhance composites manufacturability. He says Ferno's first requirement was that each leg support up to 318 kg (the iN∫X is rated at 318 kg *total*). Second, each pair of legs must accommodate, through their length, the pulleys and wires required to raise and lower the legs.

The pulleys and wires are necessitated by another important function factor of iN∫X, as Valentino notes: "Wheel set distance is constant, regardless of cot height, so the legs must adjust their position under the cot to maintain wheel distance." This gives the cot, and EMTs, a fixed and unchanging wheel position, which optimizes wheel function and maneuverability. To accomplish this, the tops of each set of legs must slide along the underside of the cot as the wheels are raised and lowered. (Leg operation is illustrated in a video available at the Ferno Web site: www.fernoems.com/inx.)

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To meet all of these design and function requirements, Bendickson and Citadel recommended a two-piece hollow design for each leg. This would allow Ferno to place pulley hardware inside the legs during assembly and allow Citadel's fabricators the ability to adjust wall thickness and other design elements more easily to meet load and weight requirements. That was a fortuitous decision. Late in the development process, Ferno decided that the weight limit on each leg should be almost doubled, to 590 kg, because designers wanted to ensure that any one leg, if absolutely necessary, would support more weight than the entire cot would ever bear. "We wanted to make sure the legs weren't the weak link," Valentino reports. This required, says Bendickson, some changes in sheet molding compound (SMC) charge placement, as well as part wall thickness increases, but was relatively easily done, given the two-piece leg concept.

Ultimately, the hollow design evolved to include, at the narrow end of the legs, an I-beam structure, which terminates at attachment points under the cot. The design also features four support arms for the legs, also made by Citadel and also of two-piece, hollow design.

Material, manufacturing options

Although the decision to go with a composite had been made early, the time had come to make specific material choices. Carbon fiber mat and unidirectional carbon fiber were evaluated, but Bendickson says carbon fiber SMC was selected because the legs "needed fiber that offered a variety of orientations for strength." Supplied by Citadel's Quantum Composites facility (Bay City, MI, US), the SMC, branded AMC 8590, features 12K tow (nominal 25.4 mm fiber length) in a vinyl ester resin matrix.

Citadel molds the leg halves in a compression-based process. It then machines holes into each half to accommodate support arm attachment points, wheel hardware, fasteners and thread-cutting screws and through-bolts, which are used to attach the leg halves together. Notably, leg halves are not adhesively bonded. Bendickson notes that hole-drilling is, therefore, particularly critical: "Close hole tolerance is needed for good holding power and service on the cot," he says.

Already introduced into the EMS market via trade show demonstrations in 2014, the iN∫X, according to Wells, has been well received. Although the iN∫X sports a bigger price tag than the conventional cots on the market, customers reportedly see its value and understand the weight-management advantages the cot provides to EMTs. "We see it as a way to not only help EMTs do their job, but as a way to extend their careers as first responders," says Wells. Ferno started shipping the first iN∫X units in January 2015. CW

ABOUT THE AUTHOR

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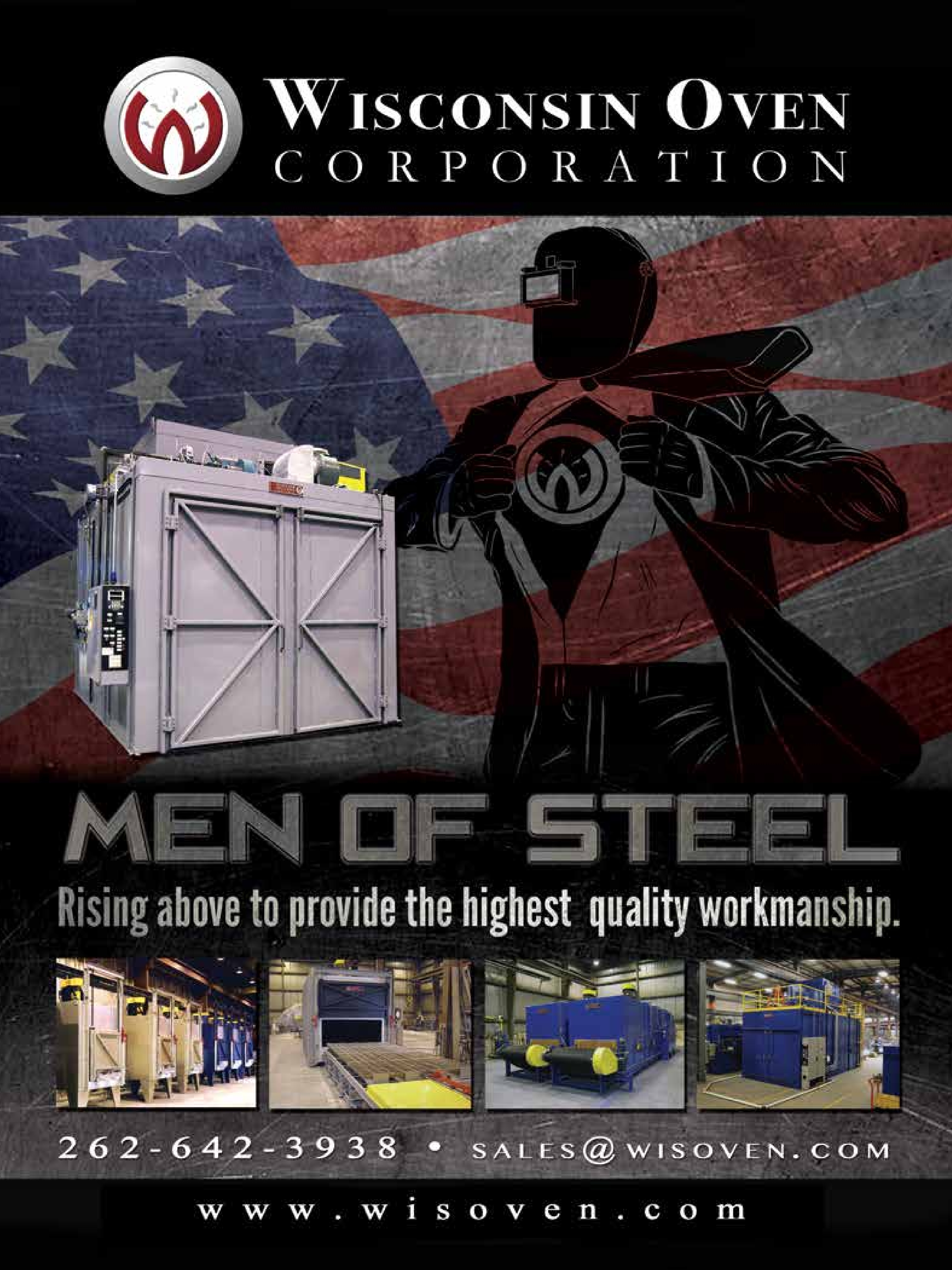
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