FEATURE

Colorado State University Rocket team builds newly designed rocket fuselage with filament winding equipment provided by Prodigm, Lattice Composites resins, and Composites One carbon fibers

Jeff Bassler

The Colorado State University Rocket team prepared for the 2019 Intercollegiate Rocket Engineering Competition (IREC) by focusing on refining the liquid fueled motor, advancing the aerodynamic design of the rocket, continuing the use of the innovative honeycomb/fiberglass composite, developing an interesting experimental payload, and successfully implementing active flight controls (Figure 1).

But this year they got sponsorship to implement a method commonly used to manufacture rocket motor housings in the Aerospace industry; filament wound carbon composite structures. This would allow them to gain further insight into methods and technologies available to the Aerospace industry (Figure 2).

Their fuselage project got its start when Prodigm, a company which focuses on filament winding solutions, retained a CSU rocket team member to assist Prodigm while developing a process for winding carbon fiber over high-end rifle barrels. While manufacturing a batch of prototypes, the team member mentioned the challenge of finding an option to replace the current rocket fiberglass fuselage. A Prodigm team member explained the advantages of switching a filament winding process for their fuselage application.

For example, filament winding places fibers around the circumference of the tube specifically to produce parts with strength in the desired directions of finished part's mechanical loads. Filament winding also provides the capability to use very long continuous carbon fibers to add additional strength and reduce overall lower cost when compared to prepreg composite options. Plus, the finished part would have no seams that could fail.

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The team member took this information back to the Rocket team and proposed the concept of filament winding to improve the fuselage using a carbon composite laminate. The team agreed that a lighter stronger fuselage would be an exciting advancement for the rocket program and to work with the Prodigm team to build it.

The Prodigm team designed an intensely hands-on-lab experience so the CSU students would explore small-scale filament-winding technology to inspire the production of larger rockets or lightweight composite parts in their future aerospace roles (Figure 3).

Carbon fiber and filament winding process

First, it was critical for team to understand how best to utilize carbon fibers for this project. The team learned that carbon fibers have its highest tensile modulus and strength in the direction of the fiber. By only placing fibers in directions where strength is desired and not placing fibers in directions where strength is not as critical, this would make finished part with a reduced weight/strength ratio compared to a part made of woven hand laid prepreg they used in the past (Figure 4).

Once the mechanical properties of the finished fuselage were specified, the CSU designers then modeled different angular laminate layups in Autodesk® Helius® and performed FEA studies on various laminate makeups using the exact specifications for their part. The software also helped the team select the optimal filament wound pattern combinations for their fuselage and couplers.

Filament winding patterns are typically grouped into two categories. When the desired strength is along the direction of the mandrel the angle of the pattern goes along the axis of the mandrel and must be repeated. This type of pattern is typically

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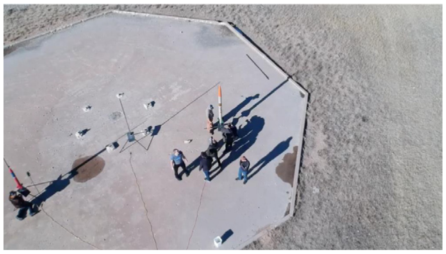

FIGURE 1

Colorado State University Rocket team tested the new rocket and fuselage before the 2019 Intercollegiate Rocket Engineering Competition (IREC).

FIGURE 2

CSU rocket assembly progress June-16 in preparation for competition.

referred to as a helical pattern. The paths of fibers are interwoven as the machine cycles from end to end of the mandrel (Figure 5).

When the desired direction of strength is perpendicular to the axis of the mandrel the fibers are placed edge to edge. This type of pattern is referred to as a hoop or circumferential wind pattern. These types of patterns provide crush strength to the finished part and are also used in between large buildups of helical patterns to squeeze or consolidate the layers of composite underneath (Figure 6).

Once the laminate angles and thicknesses were designed, the CSU team used a pattern design tool to accept the required angles and solve the count of fiber rovings required to fully cover the part and achieve the specified thickness. The pattern design software then generated a motion profile or program to be loaded onto the machine.

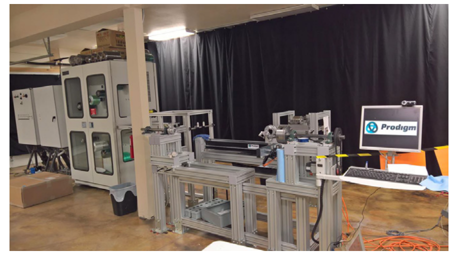

FIGURE 4

Prodigm Lab is complete with hardware and software to produce parts similar to full production line used by manufacturers.

Typically, this program is in a generic format such as a CNC program for the controller on the machine. Machines that implement a generic CNC control platform offer more flexibility for manufacturers enabling them to choose from several options of pattern design software, but also require more experienced operators. Prodigm offers both a custom CNC interface and standard generic format, the custom CNC interface is better suited for less experienced operators such as the CSU team members. This is why Prodigm recommended the team use their customized interface on the lab equipment.

This type of CNC interface is optional but offers functionalities such as connection to database for loading programs, logging of all events that occur on machine and performance metrics of production. Plus, this CNC interface leverages OPC-UA for high-speed communication with the CNC control platform and tensioning creel (Figures 7 and 8).

The students learned the benefits of control systems that are designed using all COTS components in order to maintain filament-winding equipment without concern of becoming obsolete or proprietary components. The tensioner system the team used was connected to a winding control system to manage the tension for each pattern. This type of system has a big advantage over multiple 3rd party systems that need the operator to stop the machine to make tension adjustments (Figure 9).

Once the equipment and software training was completed, the CSU team selected their carbon material to match the finished part design specifications. The fiber was delivered on bobbins of outside pull configuration. Outside pull spools are required for systems that implement an active tensioner, where inside pull spools are generally used for setups that achieve

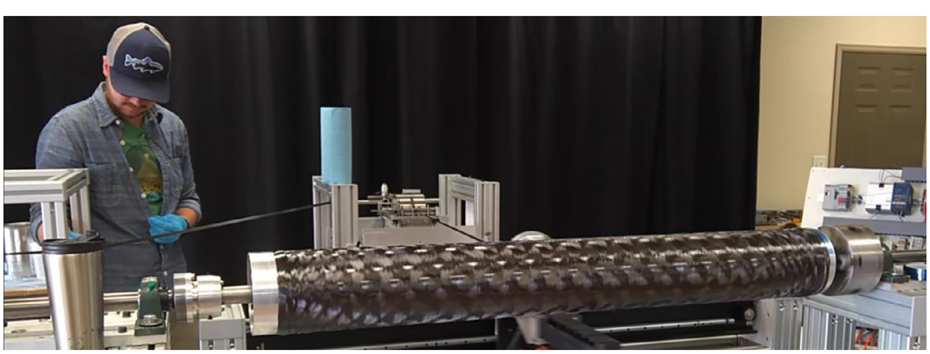

FIGURE 3

CSU rocket fuselage was built using filament-winding technology to ensure the success of the rocket.

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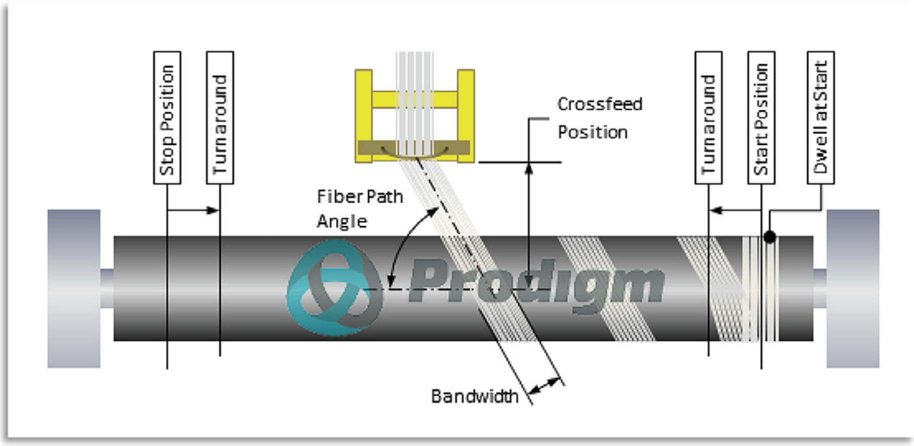

FIGURE 5

Helical Filament Winding Pattern.

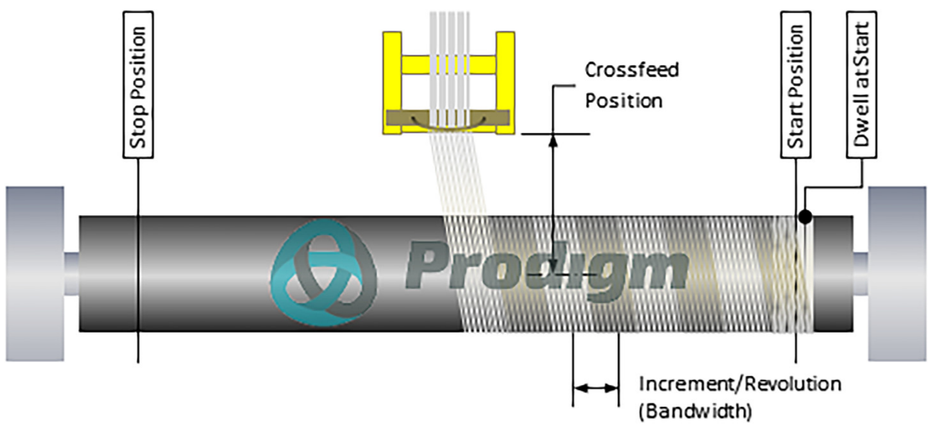

FIGURE 6

Filament Winding Hoop Pattern.

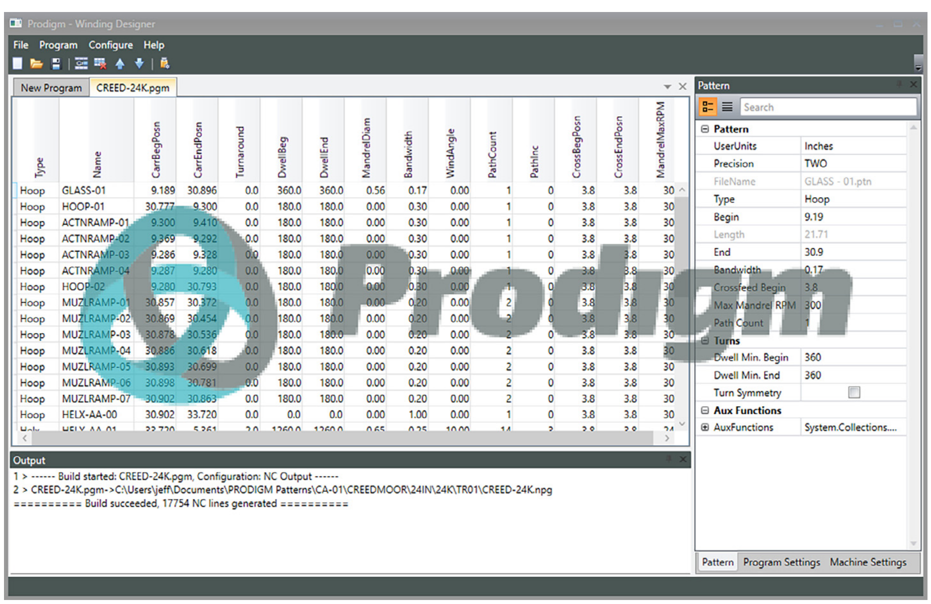

FIGURE 7

Pattern files generated in Prodigm software have been designed to be compatible with version control systems such as Subversion, that enables manufacturers to track and control revisions made to product designs through their lifecycles.

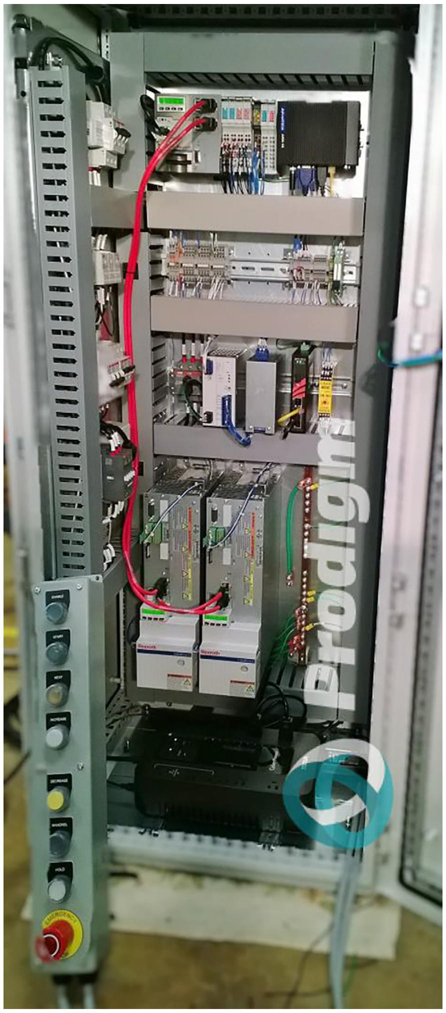

FIGURE 8

Prodigm 2-axis Winder Control System with Bosch Rexroth motors, servo drives, and controller.

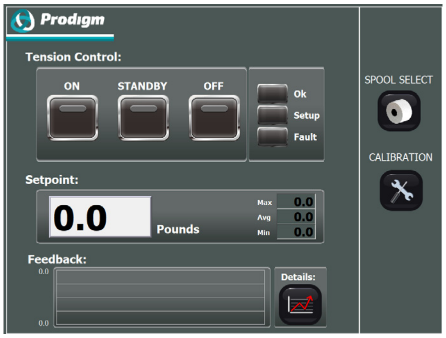

FIGURE 9

Prodigm Tensioner Interface makes it unnecessary to have to stop the machine to manually adjust the tension.

tension by dragging the glass or carbon tows over and under tensioning bars (Figure 10).

Filament winding resins

Next, the team set up resin bath for the fibers to be impregnated with the formulated resin from Lattice Composites right before winding the filament onto the mandrel. To maximize the strength properties of the Composite laminate, the amount of resin applied needed only to be enough to fully bond the carbon filaments and facilitate full consolidation of the composite laminate during the curing process.

In the Aerospace industry the ideal ratio of carbon to resin is 60% carbon by volume of laminate matrix. This ratio typically provides full bonding, more resin than this the finished part is getting heavier but not stronger, less, the finished part will be weaker due to incomplete bonding of the filaments or voids. Using a pre-set amount of tension, these continuous fibers are then strategically laid over the rotating mandrel in the desired angle (high angle is for circumferential strength, a lower angle for longitudinal strength) until the part is completed. Then the part is wrapped with a heat activated tape which shrinks at specific temperatures and then finally, the part is placed in an oven or under radiant heaters until the part is completely cured.

A single or two component epoxy, polyurethane polyester, vinylester, or phenolic resins is typically used to impregnate the filament/fibers such as glass, carbon or aramids. These particular resins are chosen because they have been proven to protect parts from impact, corrosion, extreme temperature, and internal pressure. The two main criteria when selecting resin are that the resin must be compatible with the coating of the fibers and have a temperature rating compatible with the requirements for the finished part.

When winding with dry tows and applying resin with a bath, the resin bath performance is a critical part of the winding system as it directly impacts resin ratio. The bath must also evenly

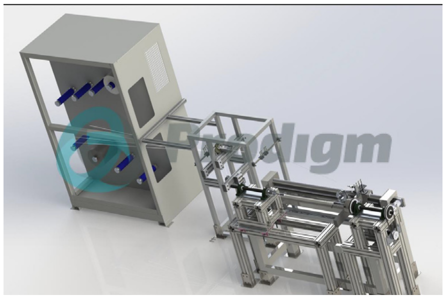

FIGURE 10

Typical filament winding equipment set up.

Feature	Benefit
No mixing (single components)	Faster throughput, easier process
Can be re-used (single components)	Less waste
Not a VOC (Volatile Organic Compound)	Less PPE
Stable at winding temperatures for 8+ hours	No time limit on winding
Customized strength, stiffness, mechanical properties	Focused towards specific applications
Mild cure	Creates crack free parts
High glass transition temperature	Keep strength in hot environments
Superior mechanical properties	Allows for smaller usage, lighter parts
Toughened	Impact resistant

FIGURE 11

Here are some of the features and benefits of the resin formulation used on this fuselage project.

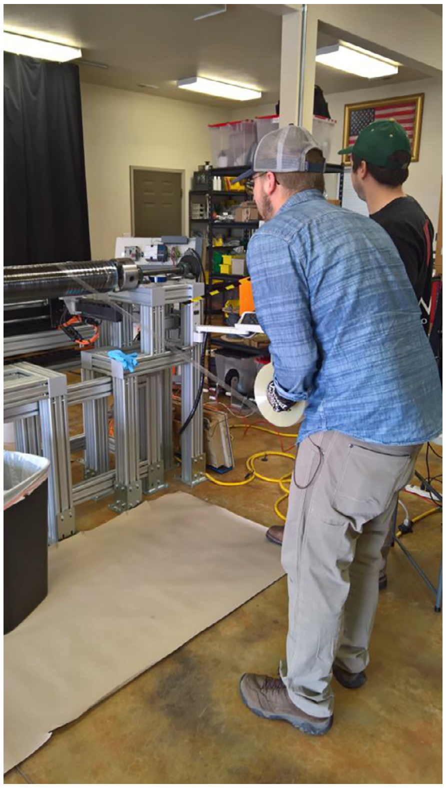

FIGURE 12

CSU rocket team manually applying shrink tape to a finished fuselage section.

coat the carbon tows with resin to achieve full wet-out and uniform bonding of the filaments. This sensitivity of the process is why aerospace applications typically require the use of pre-preg material. Prodigm chose to have the CSU Rocket team wet wind so that they could better understand the factors involved in manufacturing a filament wound composite laminate.

The CSU students wound their rocket fuselage using the LCWR-1.2 (a specially engineered two-component epoxy winding resin) donated by Lattice Composites. All of their LCWR are compatible with epoxy-sized glass and various carbon fibers. Lattice has developed single and two component winding resin systems that both provide composite parts with excellent mechanical properties. Each of the winding resin systems is highly customizable (Figures 11 and 12).

Filament winding fibers

There are many types of continuous form fibers available for filament winding. It all comes down to the end use of the product and cost. Fiberglass can be less expensive and used for product where high-performance level is not needed. Carbon fibers are usually more expensive but can tolerate very harsh conditions.

Carbon fibers may be made from several precursor materials, with polyacrylonitrile (PAN) being the most widely used raw input constituent. The crystalline structure of carbon atoms produces a fiber with high stiffness and tensile strength, and low thermal expansion. Carbon is sold in the form of tow (yarn), woven or knitted fabrics, and prepregs (pre-impregnated with epoxy or other matrix resins). While carbon fiber is more expensive than traditional glass fiber, the stiffness and strength to weight ratio is significantly higher. Carbon fiber is used in a wide variety of cutting-edge applications including aerospace, transportation, sporting goods, and many new composite applications.

The carbon fibers were donated by Composites One. The carbon fiber material used was a Toray T720SC 24 K with Tensile Strength of 5880 MPa. This is an intermediate modulus, high tensile strength fiber. This never twisted fiber has excellent tensile composite properties and is specifically designed to meet the weight saving demand of aircraft and high-performance recreational products.

https://www.toray.us/products/prod_004.html

The Colorado State University Rocket Team

Dr. Marchese founded the Colorado State University (CSU) Intercollegiate Rocket Competition (IREC) team in 2014, with a group of only four students. Today, the 2018–2019 group, co-advised by Dr. Guzik, includes 14 students with a passion for pushing rocket innovation to new heights.

The Intercollegiate Rocket Engineering Competition (IREC)

The Experimental Sounding Rocket Association and the Spaceport America Crew ESRA hosts the annual Intercollegiate Rocket Engineering Competition (IREC) with student rocketry teams from across the Unites States of America and around the world.

Prodigm

Prodigm is the premier maker of production-focused filament winding controls and software solutions. Prodigm offers CNC control system for filament winding machines. Prodigm's control system implements Bosch Rexroth motors, servo drives, and controller that enable manufacturers to access Bosch Rexroth global support network.

Lattice Composites

Lattice Composites is a custom formulator and manufacturer of advanced, high performance molding compounds, winding resins, adhesives, and specialty resins. Their superior technical expertise and broad experience deliver comprehensive solutions and quick turnaround. They custom formulate their resin systems for specific applications and performance envelopes based on specific process and product performance needs.

Composites One

As North America's leading provider of materials and technical solutions for advanced composites manufacturers, Composites One stands ready to assist, whatever the needs. Composites One carries more than 32,000 SKUs of the industry's leading raw materials and processing supplies and more than 2,000 product categories while partnering with over 600 of the best suppliers in the business.