ISAAC
Integrated Structural Assembly of Advanced Composites

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July 2024

Acknowledgements

Since acquiring ISAAC in 2014, many people have worked to make ISAAC a success. These are the primary contributors.

Erin Anderson
Alana Cardona
Jake Tury
Chris Cusson
Danny Drake
Andrew Lovejoy
Ramy Harik
Ray Grenoble
Ted Johnson
Peter Juarez
Elizabeth Gregory

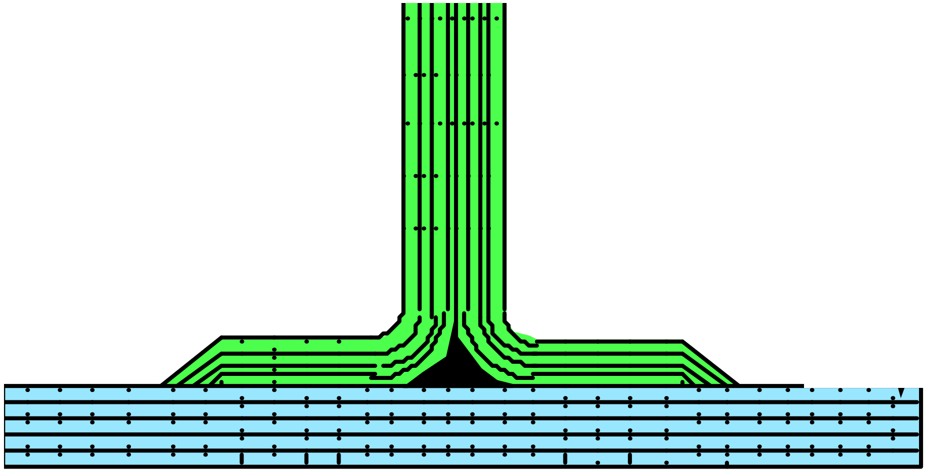
Adam Przekop
Brian Grimsley
Kevin Bonilla
Nancy Holloway
Thuan Nguyen
Amanda Pettit-Pokora
Joe McKenney
Chauncey Wu
Brian Stewart
Rob Martin
Many people from Electroimpact
Many people from CGTech

Presentation Outline

- Why use composites
- Background and general description
- Projects
  - Automated fiber placement (AFP)
  - Through-thickness stitching

What are structural composites?

- What are structural composites?
  - Component made from multiple different materials
  - Wood
  - Carbon-epoxy
  - Fiberglass
  - Typically layered, anisotropic



Layers

Why Composites for Aerospace?

- Advantages of composites over aluminum
  - Lighter and stiffer
  - Opportunities to tailor structure to meet loading requirements
  - Enable high aspect ratio wings due to their superior stiffness (leads to aerodynamic benefits)
  - Could lead to thinner wings with less sweep (aerodynamic benefits)
  - Low coefficient of thermal expansion so experience less deformation and stress due to thermal changes

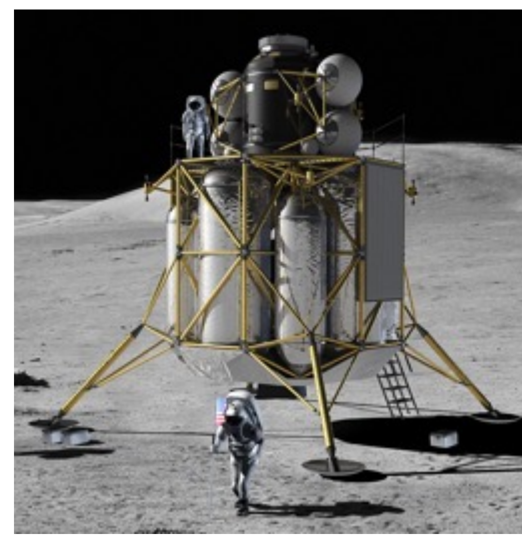
What is ISAAC

- ISAAC is a highly accurate, robotic platform for automated composite manufacturing
- Supports research on the design, analysis, fabrication, and evaluation of advanced composite materials and structures
- Designed and built by Electroimpact* based on a commercially available KUKA KR1000 L750 robot
- ISAAC is located at the NASA Langley Research Center

* The use of trademarks or names of manufacturers is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by NASA

Why ISAAC at NASA

- To explore new manufacturing methods and designs in a research environment to support lighter, safer, and structurally optimized aircraft and spacecraft structures
- Develop and evaluate methods on a small scale and move to a larger scale in-house
- Rapidly transfer knowledge to the aerospace industry for application to flight hardware and commercial products



Robotic System

- Six degree-of-freedom robot
  - 40-foot-long linear track system
  - Integrated carriage with 30 feet of travel
- Several end effectors for flexibility for performing various tasks
- New capabilities can be achieved through development of additional end effectors

Robot

End effector

Layup table
- 6 ft by 12 ft
- Grid pattern for positioning

Rotary table
- Top plate options of 3 ft and 6 ft diameters
- 20,000 lb capacity
- Rotation up to 5 rpm with acceleration time 0-180 deg.: 6 secs.
- Indexing precision of ± 10 arc-secs. and repeatability accuracy of ± 10 arc-secs.
- Numerous attachment points for part or tooling

Track

Computer Controlled

- Operated using Electroimpact software control panel and hardware interface
- Operating programs created using the software packages by CGTech
  - Vericut Composite Programming (VCP) can read step files (STP), native Pro-Engineer part files, and native Solidworks part files
  - Vericut Composite Simulation (VCS) uses the posted information from VCP to check for machine issues or interferences
- Direct robotic programming instructions through G-code
- For complex parts, typical procedure includes computer simulation and slow dry run to ensure the simulation matches reality



Fabrication Capabilities

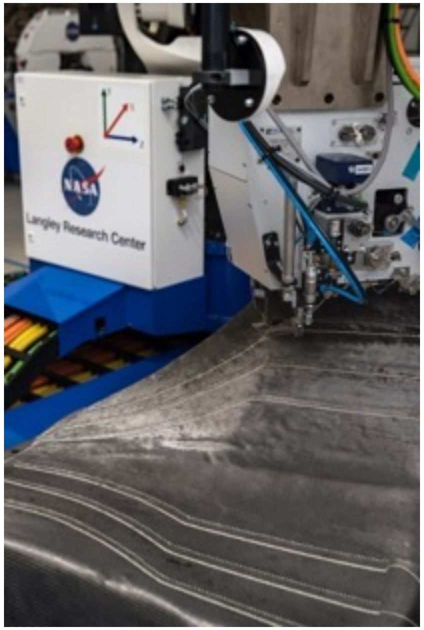
Automated Fiber Placement (AFP)

- State-of-the-art for aerospace
- Carbon-epoxy prepreg layers

Through-Thickness Stitching

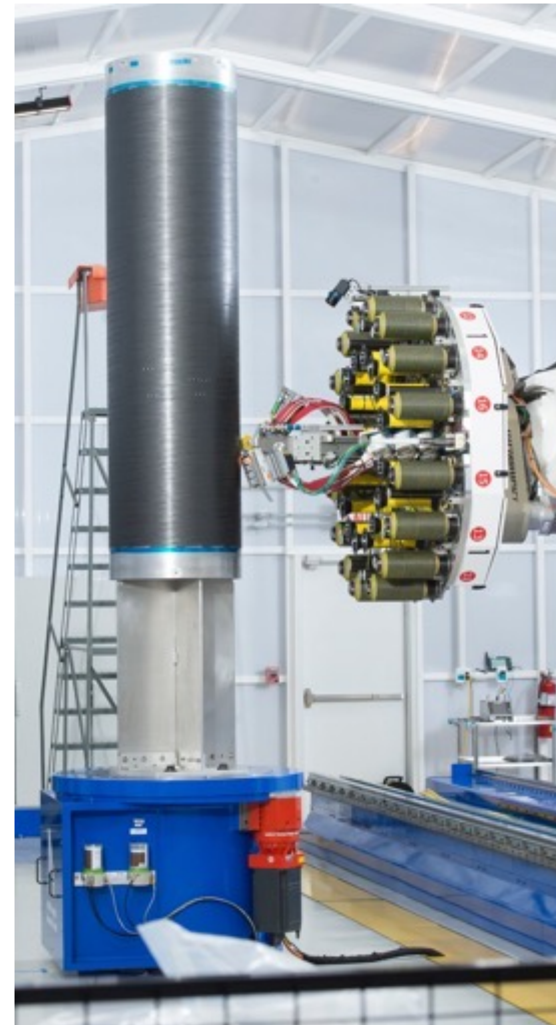
- New manufacturing method
- Dry carbon fabric with infused resin





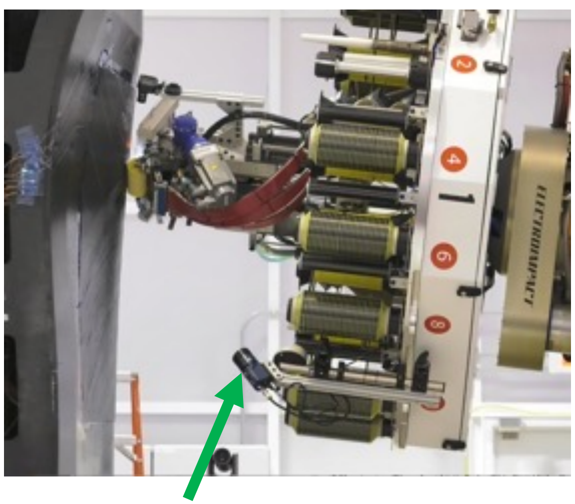
AFP on ISAAC

- Up to 16 spools of ¼-inch-wide prepreg tows
  - Courses contain 1 to 16 tows
  - 4-inch-wide compaction roller
- Alternate assembly with maximum 8 tows and 2-inch-wide roller
- Laydown rates from 100 in/min. to 2000 in/min.
- Flat panels up to 5 ft by 11 ft
- Complex parts with special-purpose tooling
- Cylindrical or other similar shapes on rotator up to 5-ft diameter
- Rotator programmed to move with robot

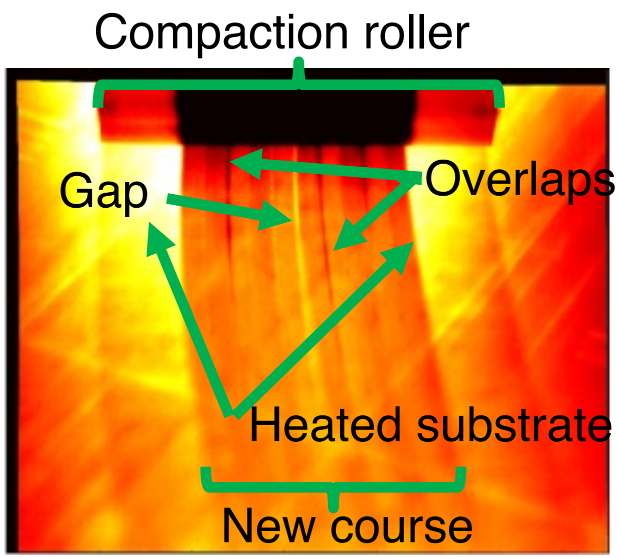


In Situ Quality Assessment with Thermography for AFP

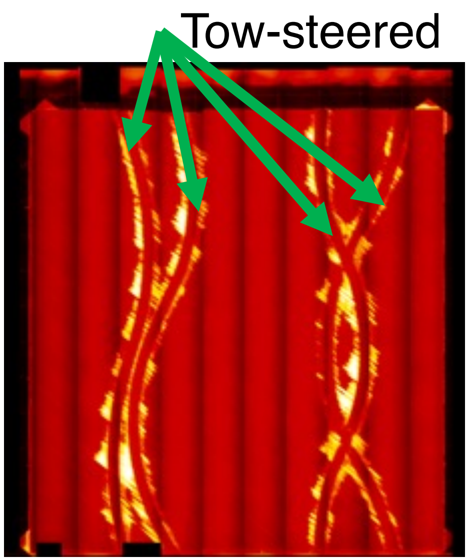
- Infrared (IR) imaging offers opportunity to catch defects quickly and alert the operator as soon as tow is placed
- IR camera used as the tows are placed or by scanning the complete surface after each layer is placed
- AFP heater provides heat source
- Temperature variations provide qualitative indication of surface contour (laps and gaps) and consolidation quality of uppermost ply interface



Thermal camera



Thermal frame collected during placement

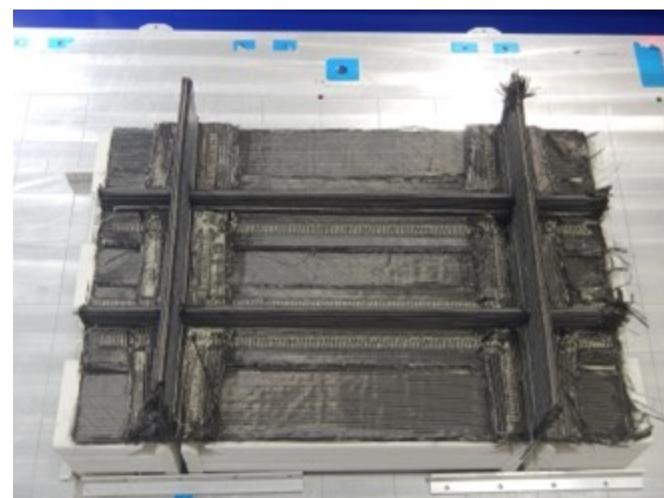


Reconstruction of a full ply line scan

Through-Thickness Stitching on ISAAC

- Two stitching heads
  - Fabricated by PFAFF Industriesysteme und Maschinen GmbH Branch Office KSL (Lorsch, Germany)
  - Incorporated onto ISAAC robot by Electroimpact
- Operation
  - Vericut software by CGTech with hardware interface by Electroimpact
  - Additional control algorithms developed in-house
  - Robot control macros defined by LaRC and implemented by Electroimpact

Stitching heads



Stitched stiffened panel

Clean Room Environment

- International Organization for Standardization (ISO) Class 7
- Excellent temperature and humidity control
  - 65°F to 85°F ± 2°F
  - 50% RH to 80% RH ± 5%
- Retractable sections on rail system for moving large hardware inside
- 70-ft long, 41-ft wide, 17-ft tall

Projects

- Composite Technology for Exploration (CTE) sandwich panels
- Advanced Composites Project (ACP) defect studies, thermography
- Space Technology Announcement of Collaboration Opportunity (ACO) Program with Generation Orbit Launch Services, Inc. for a task titled, “Advanced Design and Manufacture of Cryogenic Propellant Tanks”
- Advanced Air Transportation Technologies (AATT) tow steering, alternate stitching threads
- Convergent Aeronautics Solutions (CAS) thin ply, Subsonic Single Aft Engine (SUSAN) aircraft concept
- Human Landing System (HLS) lunar lander strut
- Aeronautics Research Mission Directorate (ARMD) wind tunnel blades
- High-Rate Composites Aircraft Manufacturing (HiCAM) stitched structure, bonded structure, design for manufacturing
- Transonic Truss Braced Wing (TTBW) development article

Partners

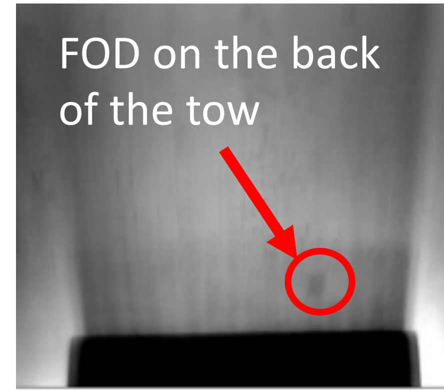
- The Boeing Company
- Spirit Aerosystems
- Generation Orbit Launch Services
- University of South Carolina
- Mississippi State University
- NASA Marshall Space Flight Center (MSFC)
- NASA Goddard Space Flight Center (GSFC)
- Electroimpact
- CGTech

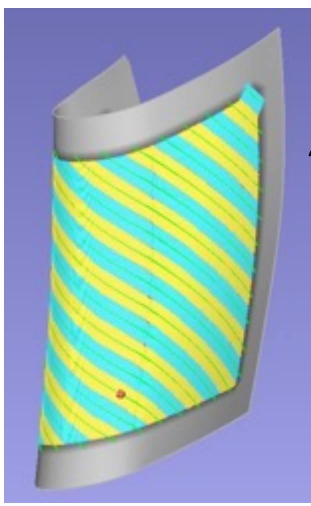
AFP

AFP Video

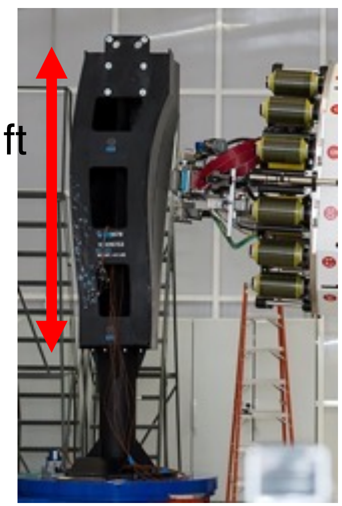
AFP Defects

- Evaluate manufacturing defects inherent in the AFP process
- Use material and process representative of what industry uses on aircraft today
- Application by hand or by programming
- Tracking and understanding manufacturing-induced defects can lead to improved-quality parts
- In situ thermography





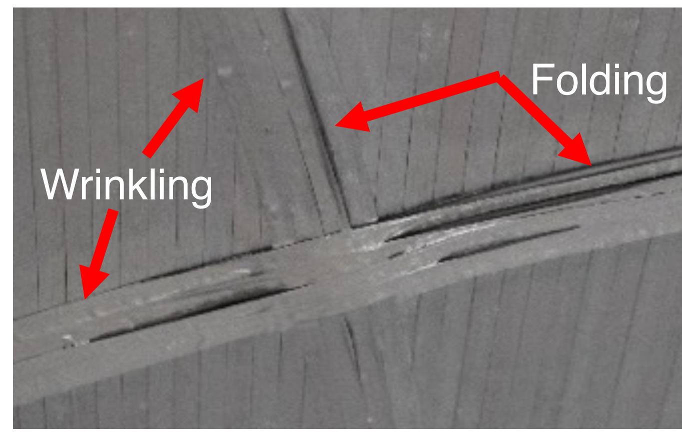
~ 5 ft

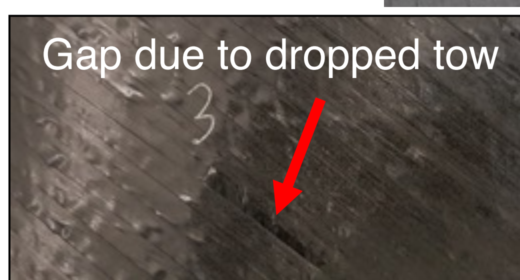


Computer simulation

Placement

Concave and convex surfaces

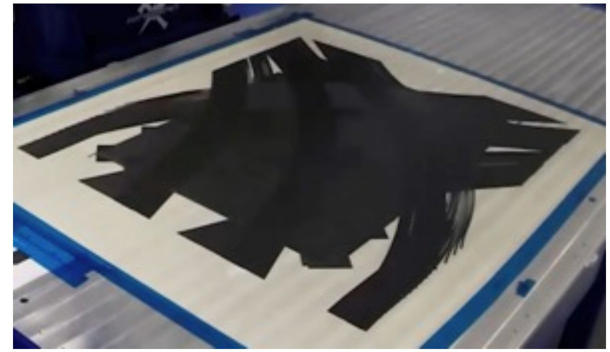




Defects

Tow Steering

- Lighter structures can be achieved by locally tailoring fiber orientation
- Structurally efficient design to optimize load paths for expected flight loads
- Wrinkles, puckers, overlaps, gaps



Arcs used to evaluate effect of radii

Simulation of tow paths

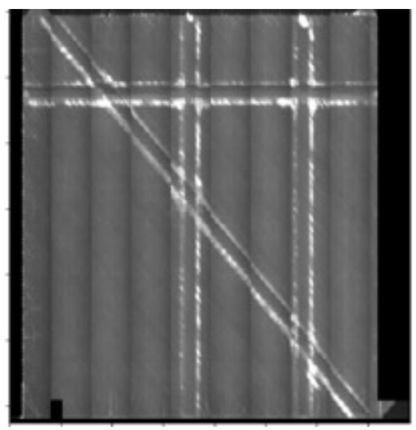
Material placement

Tailored designs

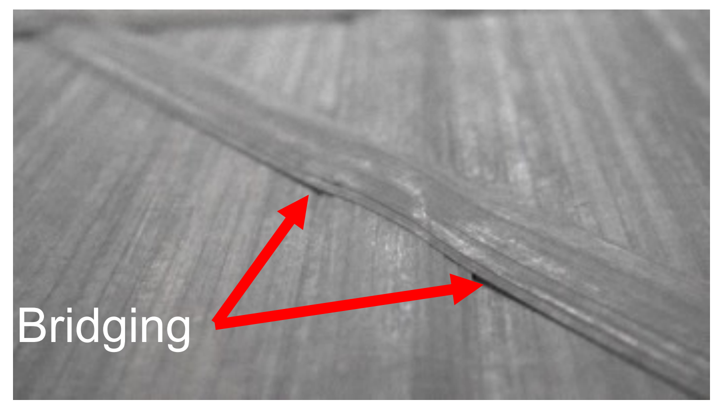
Integral Stiffening

- Adding narrow courses between full-panel courses can create integral stiffeners where needed to increase buckling loads and reduce stress concentrations
- Bridging occurs on edges of stiffeners
- Debulking significantly reduces bridging

Final cured panel



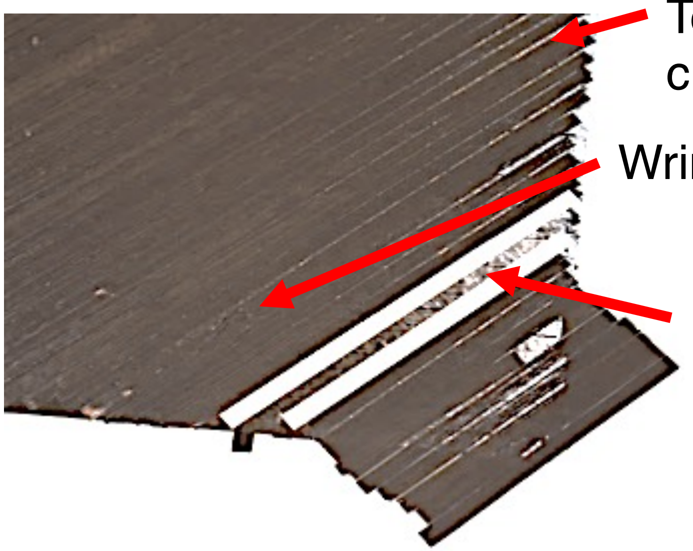
Thermography shows trapped air as brighter regions



Close up of stiffener intersection

Thin Ply Tow Placement

- Thinner layers open the door to lighter structures, increase tailoring options, and may suppress some failure mechanisms
- Typical towpreg fiber areal weigh of 145 gsm to 190 gsm; 70 gsm and 30 gsm “thin-ply” material was evaluated
- Increased applied heat and reduced feed rates resulted in high quality 70-gsm panels
- 30-gsm material was too fragile to be fed through machine and modifications to the backing removal system and changes to placement parameters did not solve problems



Tow width variations created gaps

Wrinkled tows

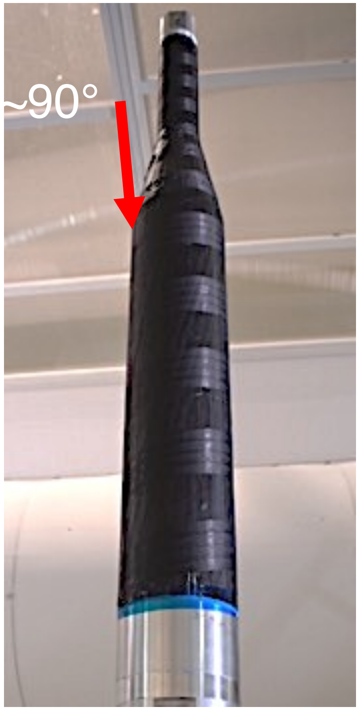
See-through tows have low local resin content

70 gsm

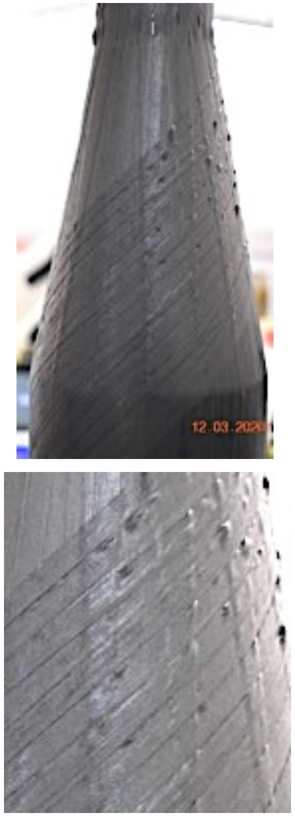
30 gsm

Tapered Lunar Lander Strut

- Numerous struts meet at a single node on the lunar lander, requiring tapers
- Lightweight optimized design must consider manufacturing defects



15°

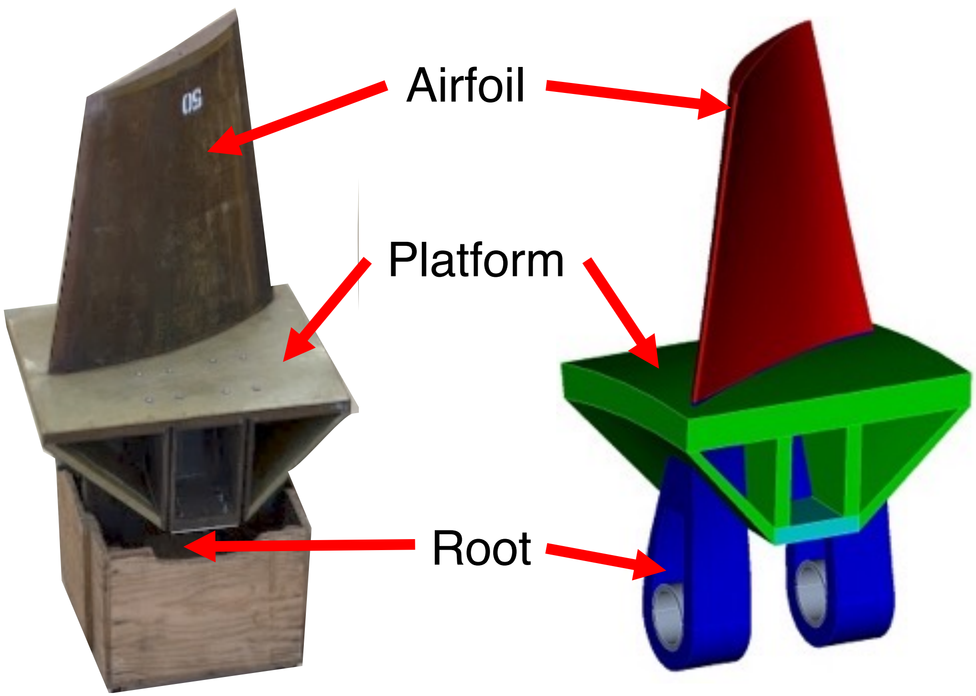


45°

90°

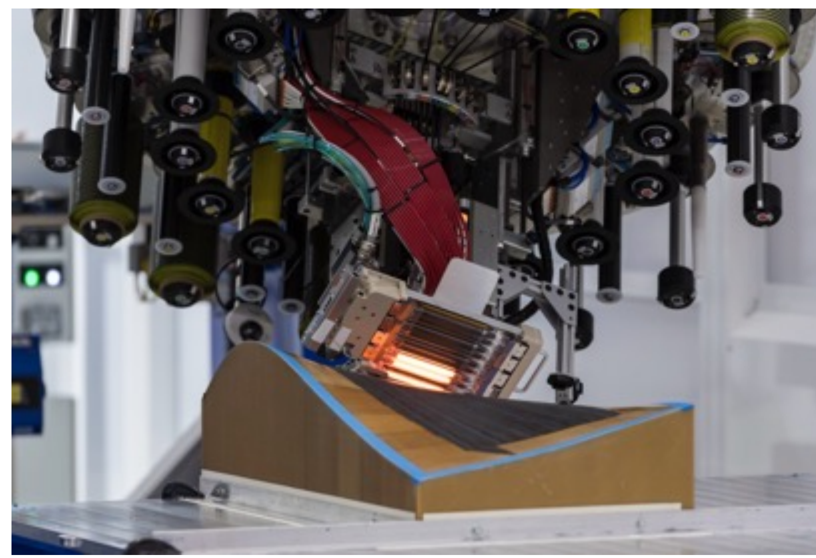
Wind Tunnel Blades

- Due to the lack of a full set of spare blades, NASA is only one accident away from shut down of the National Transonic Facility for a year or more
- Replacing wooden or fiberglass wind tunnel blades with carbon-epoxy blades could reduce the weight and cost of new blades
- Complex shape poses a challenge for the roller and heater



Blade

Model



Placement on representative-shape tool

Through-Thickness Stitching

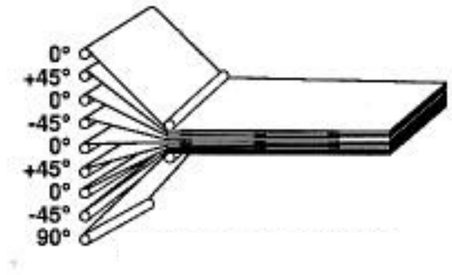
Through-Thickness Stitching Benefits

- Traditional layered composites such as those created with AFP
  - Weak in the thickness direction
  - Frequent delamination from tool drops or in-service impact damage
  - Extra material and fasteners to arrest damage growth
  - Need fasteners to combine many pieces for final part
- Stitching through the thickness increases pull-off loads, improves damage tolerance, removes the need for fasteners, and reduces final assembly time through unitization
- Stitching methodology employed in NASA-Boeing activities
  - Advanced Composites Technology Program (ACT)
  - Environmentally Responsible Aviation Project (ERA)
- Large panels with no fasteners successfully built by Boeing (2014)

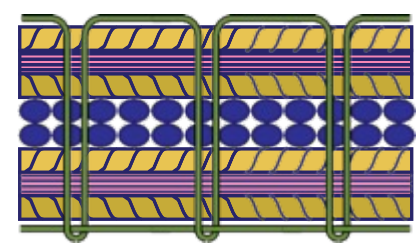
30-ft-long stitched panel with no fasteners

Creating a Stitched Part

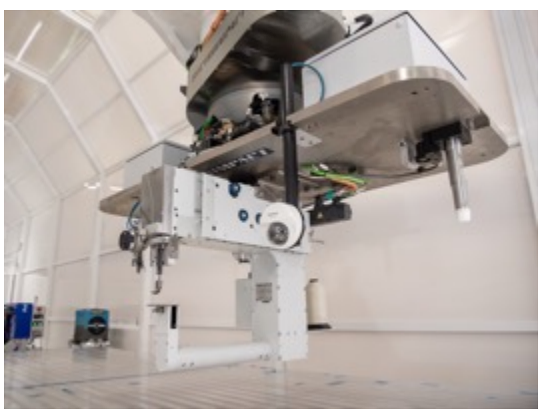
- Preform created with dry carbon fabric
- Stitch through the thickness of the fabric
  - Double-sided stitching
  - Single-sided stitching
  - Typically use Vectran thread
  - Carbon nanotube, quartz threads possible
- Infuse with thermoset resin in an oven with vacuum pressure



Combine dry fabric layers into "stacks"



Stitch stacks of material



Double-sided

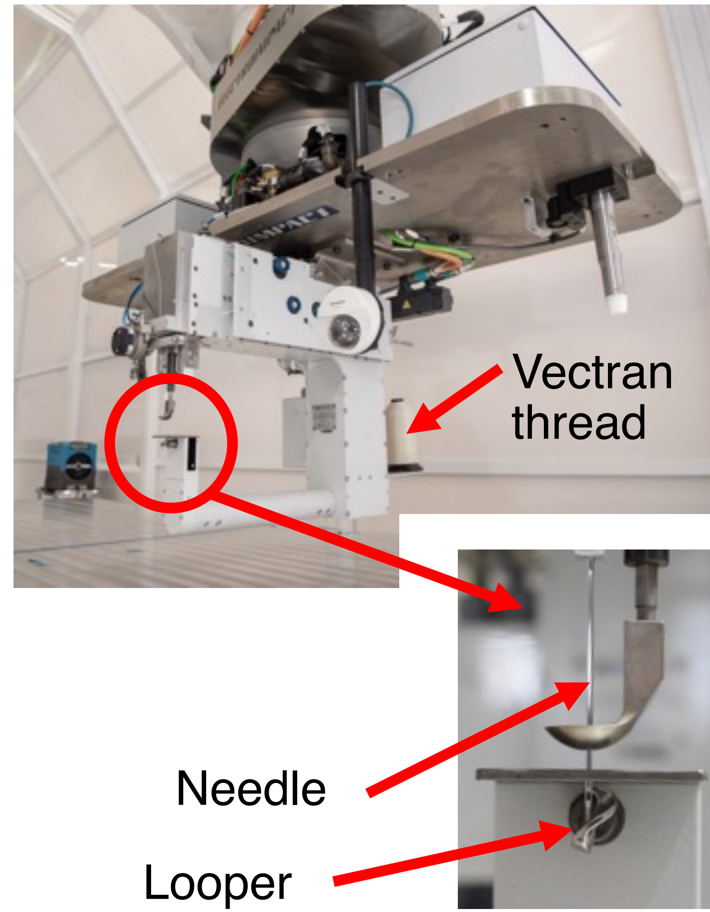
Single-sided

Double-Sided Stitching Capability

- Used for small parts and near edges
- One needle
- Minimal tooling
- Chain stitch
- Stitch rate up to 340 stitches/min.
- Preform thickness up to 0.78 in.

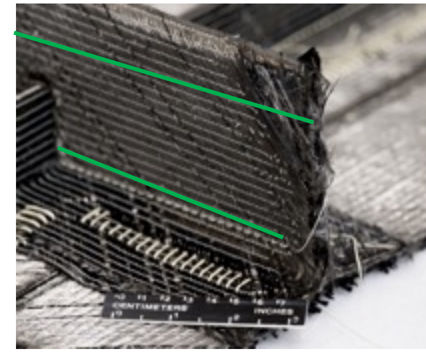
Needle side

Looper side

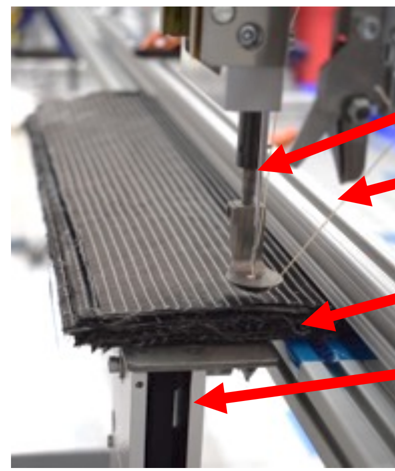


Double-Sided Stitching

- Simple supporting framework holds preform during stitching
- Limit on reach into preform
- Complex stitch paths can be programmed and implemented



Pendant to stop and start stitching and control speed



Needle

Thread

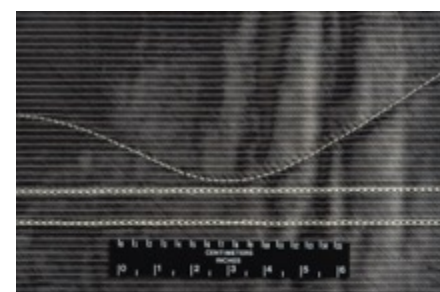
Preform

Stitching head

Throat limits how far from the edge you can stitch

Preform

Tooling framework

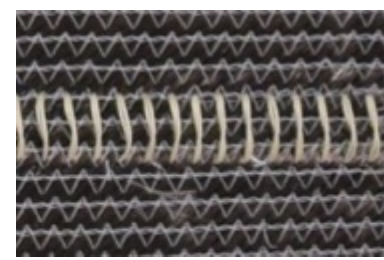


Single-Sided Stitching Capability

- Large and complex parts and stitching away from edges
- Capable of stitching dry three-dimensional (3D) preforms from one side of the part
- Tooling provides support underneath
- Insertion needle at a 45-degree angle to the preform
- Catcher needle perpendicular to preform
- Modified chain stitch
- Stitch rate up to 100 stitches/min
- Preform thickness up to 2 in.

Catcher needle Insertion needle

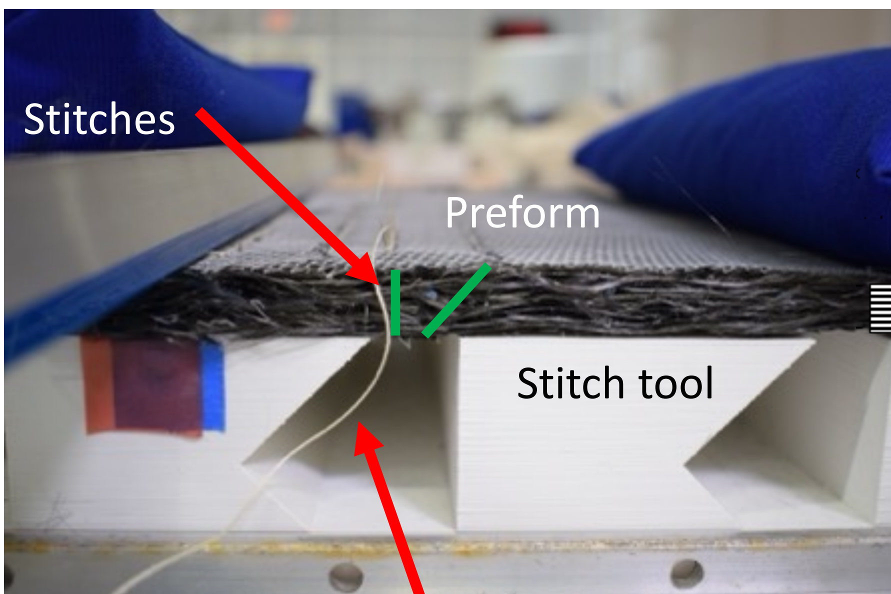
Needle side

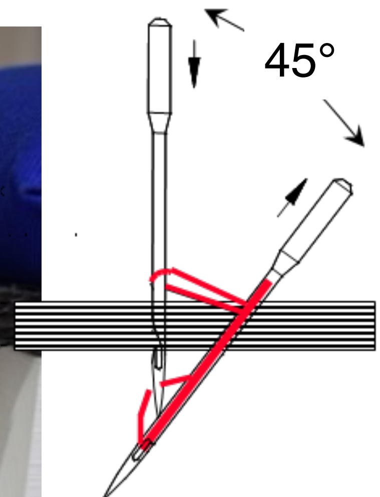


Tool side

Single-Sided Stitching

- Need access to one side of preform with cavity for needles on the other side
- Complex tools can be 3D printed or cut from foam or wood
- Program stitch paths
  - Touch probe and straight lines (Boeing method during ERA)
  - CAD with VCP or directly in G-code (ISAAC)
- Complex stitch paths can now be programmed and implemented



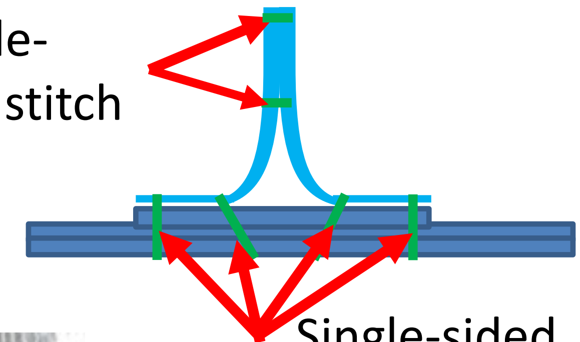


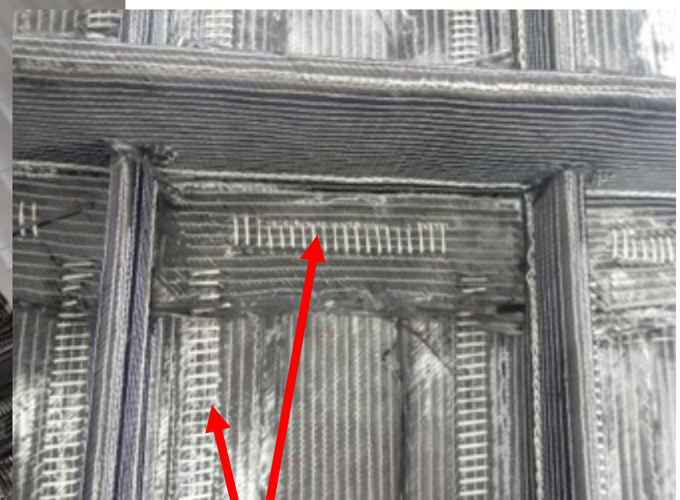
Complex Shapes

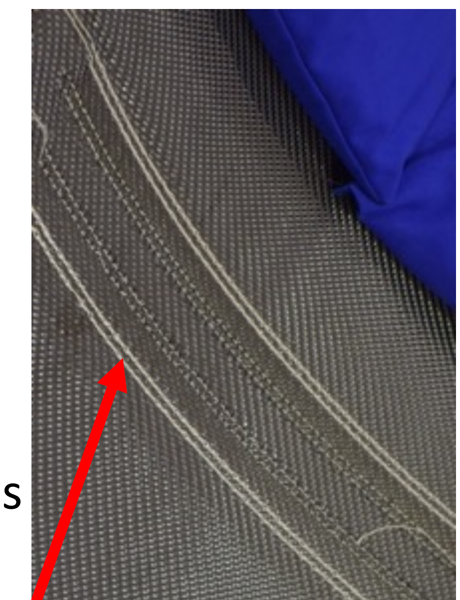
- Complex curvature tools can be used for single-sided stitching
- Smooth curves in 3D space
- Slope discontinuities when joining curves can be programmed

Unitization

- Stiffener-to-skin stitching
  - Edge of flanges
  - Multiple stitch rows (overlapping seams)

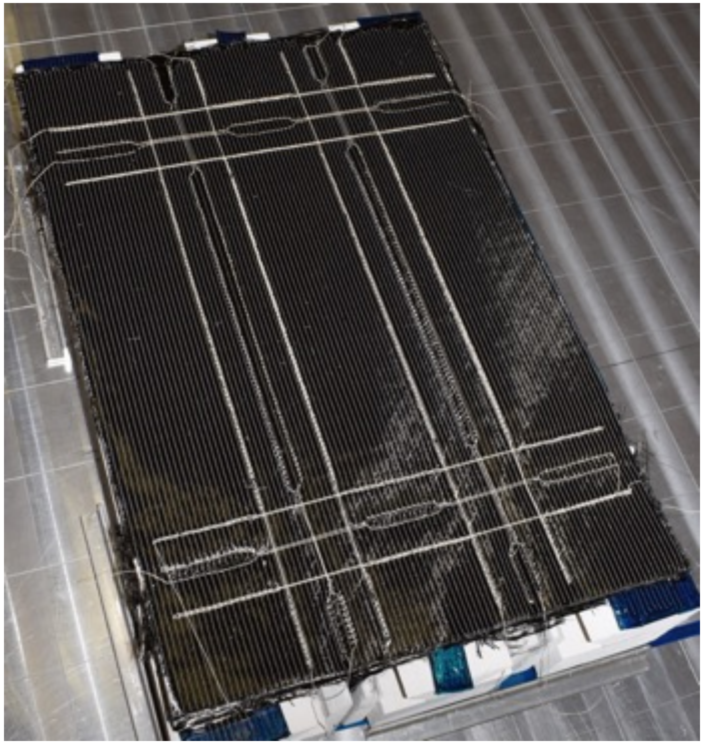






Increase Speed of Assembly

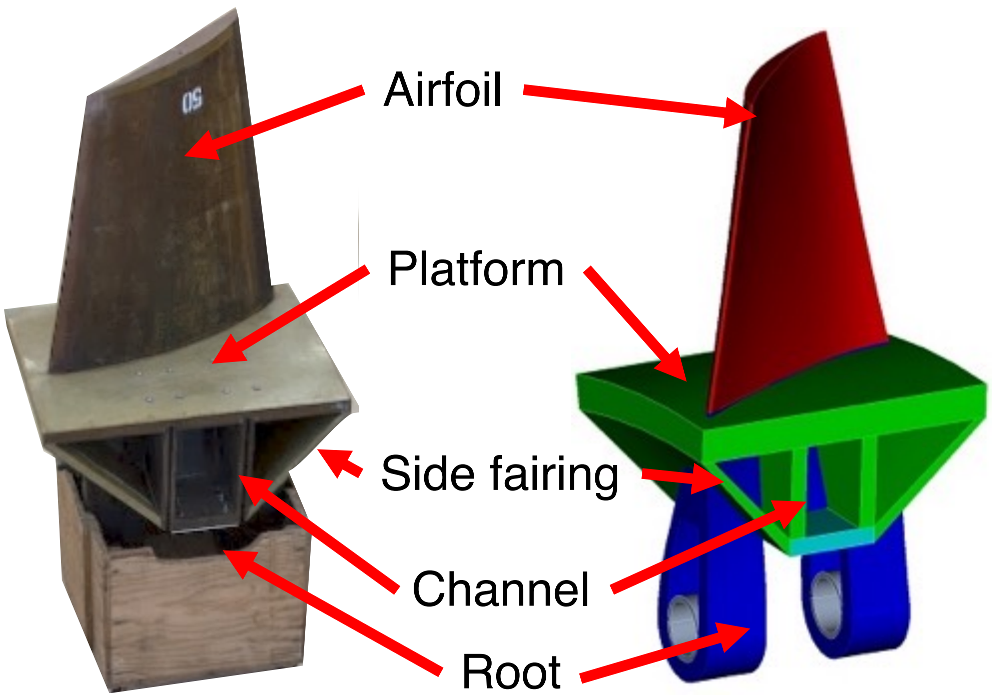
- Stiffener-to-skin stitching
  - Biaxially stiffened
  - Jumping continuous seams
    - No need to take time to cut threads while stitching



Wind Tunnel Blade Unitization

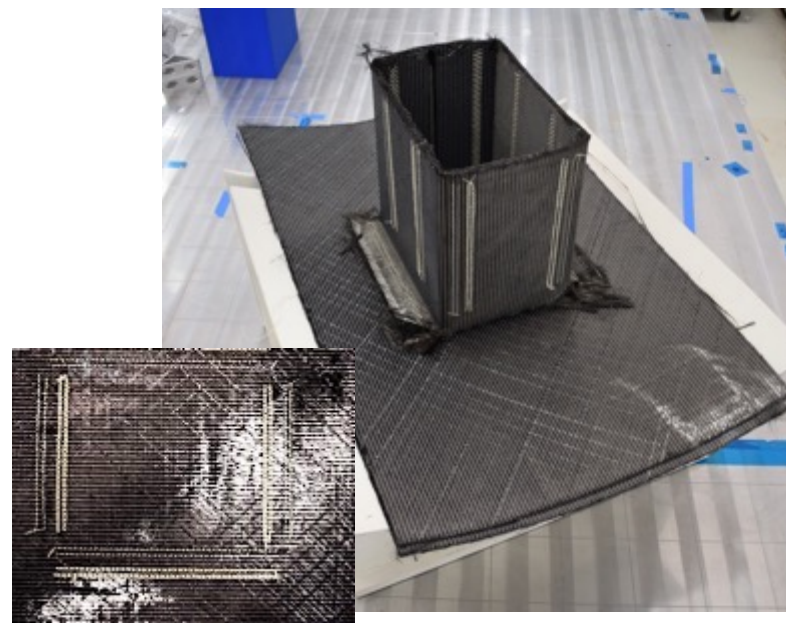
- Complexity and cost stem more from the support structure than the airfoil
- Stitching together airfoil with smaller pieces and infusing as one unit would result in a unitized part.
- Origami-like construction designs explored

Box flanges inward on tool



Blade

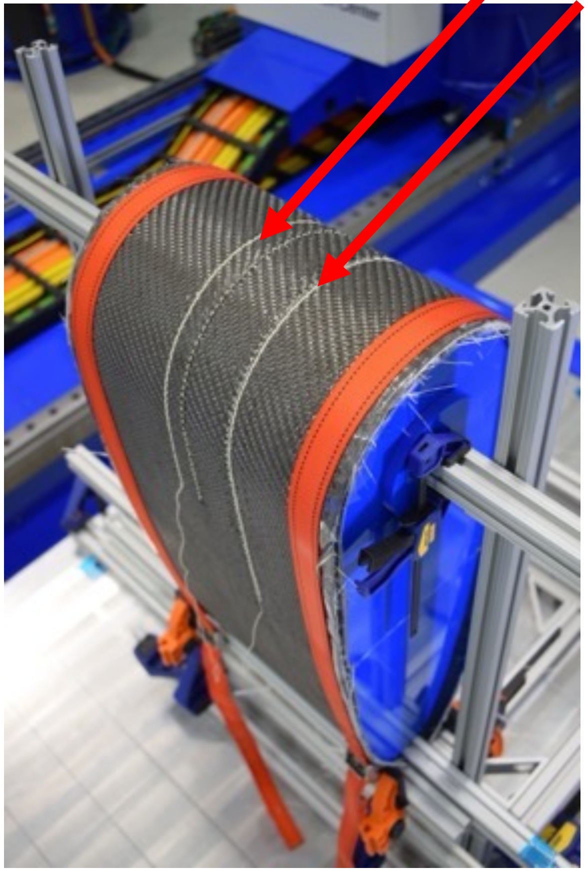
Model



Outward flanges stitched to skin

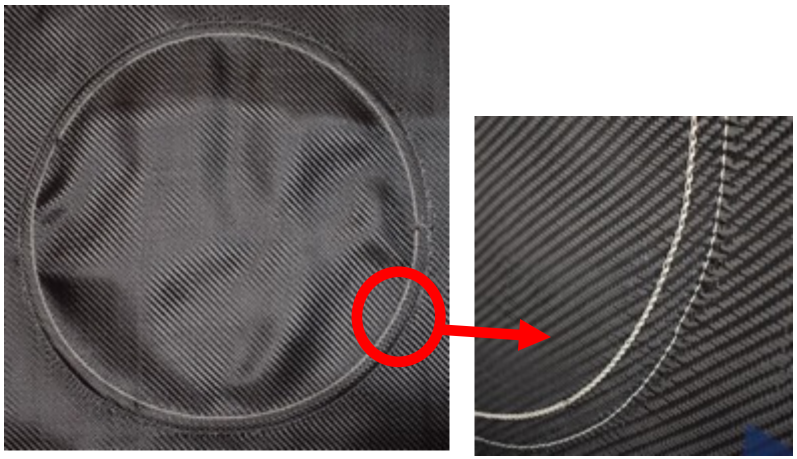
Wind Tunnel Blade Airfoil

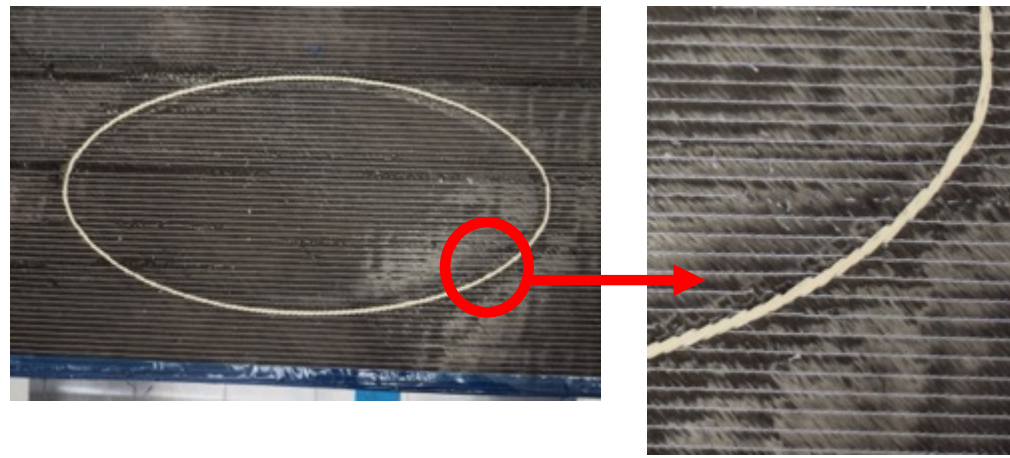
- Single-sided stitching over a thin, curved surface
- Capability needed for blade root

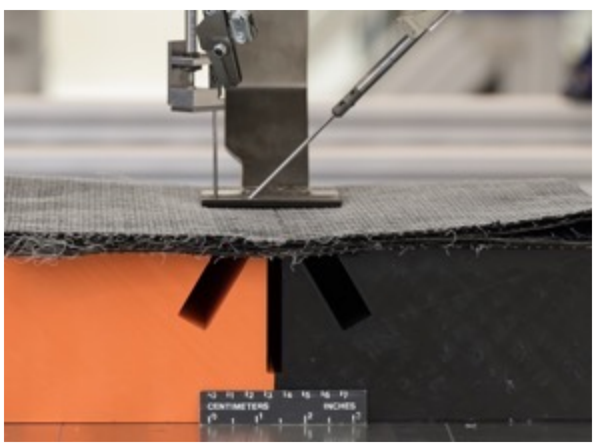


Narrow Seams (Side-Slip Stitching)

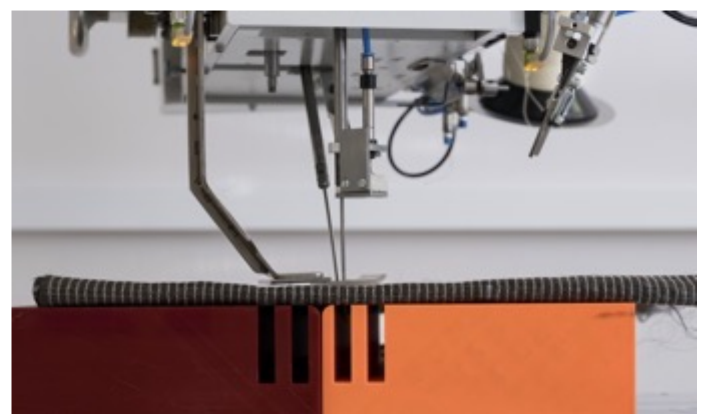
The spacing between the thread paths can now be modified by rotating the needles relative to the forward motion of the head







Traditional stitching



Side-slip stitching

Stitching Video

Future Capabilities

- Blank "development" head
  - Breadboard for integration of new technologies with ISAAC system
  - Ready to interface with air, electrical power, data
- Modification to existing AFP head task awarded
  - Carbon/thermoplastic spools
  - Variable spot size laser to replace IR heater
  - Plans developed to modify clean room to make it "laser-safe"

Development head

Impact of ISAAC

- AFP
  - Developed a better understanding of structural behavior of AFP parts using state-of-the-art techniques
  - Supported development of in situ thermography techniques
  - Quantified and explored the consequence of manufacturing defects
  - Developed manufacturing technology to support new and less commonly used designs such as tow steering and integral stiffening
- Through-thickness stitching
  - Developed a better understanding of structural behavior of stitched parts
  - Developed complex curvature control path algorithms
  - Invented side-slip stitching to allow narrower seams
  - Developed stiffener jumping technique to speed stitching process
  - Developed new tooling approach to eliminate need for fiberglass preform support

Concluding Remarks

- ISAAC is a research platform that scales directly to industry practice
- Flexible system architecture allows the addition of alternate end effectors and new manufacturing methods
- ISAAC provides a state-of-art composites manufacturing capability
  - Ideal to conduct research to improve and expand AFP methods and designs that are implemented by AFP
  - Ideal for developing through-thickness stitching technology
- ISAAC has supported numerous aircraft and spacecraft projects