Automated Ply-by-Ply Lamination and In-Situ Consolidation of Dry Carbon Fiber Non-Crimp Fabrics for High-Rate Aircraft Manufacturing of Structural Aircraft Components

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Welcome

<u>Kris Benson</u>

- Northrop Grumman Aerospace Structures
- Research and Development Engineer
- 3 years in composite process engineering
- Hobbies: desert adventures (long range rifle shooting), surfing, & skateboarding

Outline

- Introduction
- NCF
- ASF
- Problem Statement
- Compaction Trials
- Preforming Trials
- Material Observations

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Introduction

- HiCAM – Hi-Rate Composite Aircraft Manufacturing
  - Develop high-rate composite manufacturing technologies for primary airframe structures
    - Up to 80 aircraft/month
    - Reduced cost
    - No weight penalty
    - Demonstrate TRL/MRL 4, working toward TRL/MRL 6

80 aircraft/month requires a paradigm shift in traditional composite aerostructure manufacturing technologies

Resin Infused Composites

- Fabrication for Assembly
  - Dry fiber, resin infusion technology enables manufacturing of unitized structures
    - Closed mold resin transfer molding (RTM) results in repeatable, integrated structures
      - Integrated structures → reduced assembly steps → reduced manufacturing cost
      - Repeatable dimensions → shimless assembly → reduced manufacturing cost
      - Reduced fastener count → reduced assembly weight & cost

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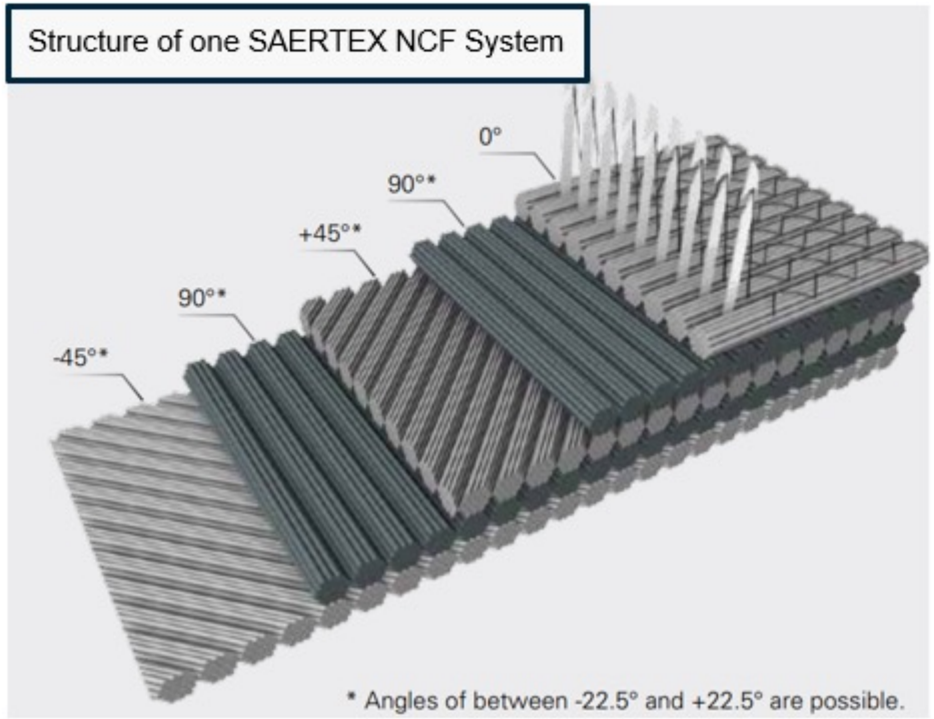
Non-Crimp Fabrics

- Multi-axial fabrics enable high-rate production
  - Fast lay-down rate of material
    - Multiple plies at once
  - Multi layered plies stitched together
  - Non-woven format = ↑ properties
  - Binder and/or veil between layers
    - When heat activated – stabilizes the NCF laminate



Saertex Multi-Axial NCF Construction Diagram

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Dry NCF Preforming

- Closed mold resin infusion (RTM) processes rely on consolidated preforms for rate manufacturing
  - Dry fiber NCF materials formed and compacted into shape
    - Results in high quality laminate
    - Bulk removal ensures easy loading into cure mold
    - Stable debulked laminates key to subsequent automated trimming
    - Stable, consolidated preforms can be safely transported and handled
    - Preforming operations can occur in parallel to cure operations to enable high-rate production

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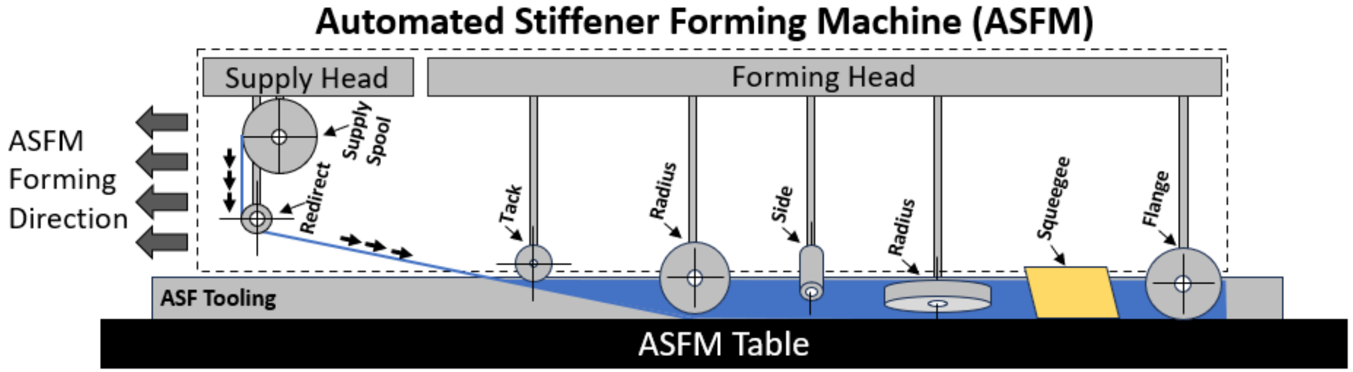
Automated Stiffener Forming (ASF)

- Northrop Grumman patented process
- Automated ply-by-ply, progressive roll forming
  - Current technology used for thermoset stiffener production
    - Mature technology producing up to12 aircraft per month
  - Capable of forming high contour aircraft stiffeners
    - Omegas, T-Stringers, Z-Stiffeners, Z-Frames, C-Spars
  - ASF adapted for NCF materials

ASFM Used for Production Thermoset Stringers



ASF Progressive Roll Forming Conceptual Diagram

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Problem Statement

- Determine ASF equipment modifications and process parameters to produce near-net thickness stiffener preforms from NCF materials
  - Define temperature and pressure requirements to process various NCF materials
  - Apply prepreg ASF lessons learned to develop dry fiber ASF technology to build high-contour stiffener preforms

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Experimentation

- Various NCF materials evaluated
  - Single layer UD, biaxial, triaxial, quad-axial
  - Typical NCF constituents: stitching, veil, binder
- NCF construction drives process parameters

NCF Materials Recently Evaluated with ASF Process

Manufacturer	Format	Carbon Fiber Areal Weight (gsm)	Binder and/or Veil in Construction
Hexcel	UD	240	No binder or veil
Saertex	UD	240	Binder
Teijin	Biax	480	Binder and veil
Hexcel	Biax	300	Veil
Saertex	Triax	817	Veil
Hexcel	Quad	760	Veil
Saertex	Quad	760	Veil

Compaction Trials

- Compaction process parameters developed on flat panels
  - Target 0% bulk factor (BF%)
  - Temperatures ranged from 23 °C (70 °F) to 180 °C (356 °F)
  - Low and high consolidation pressures tested
  - Laminates cooled to room temperature after compaction

NCF Laminate After Consolidation

NCF Laminate Before Consolidation

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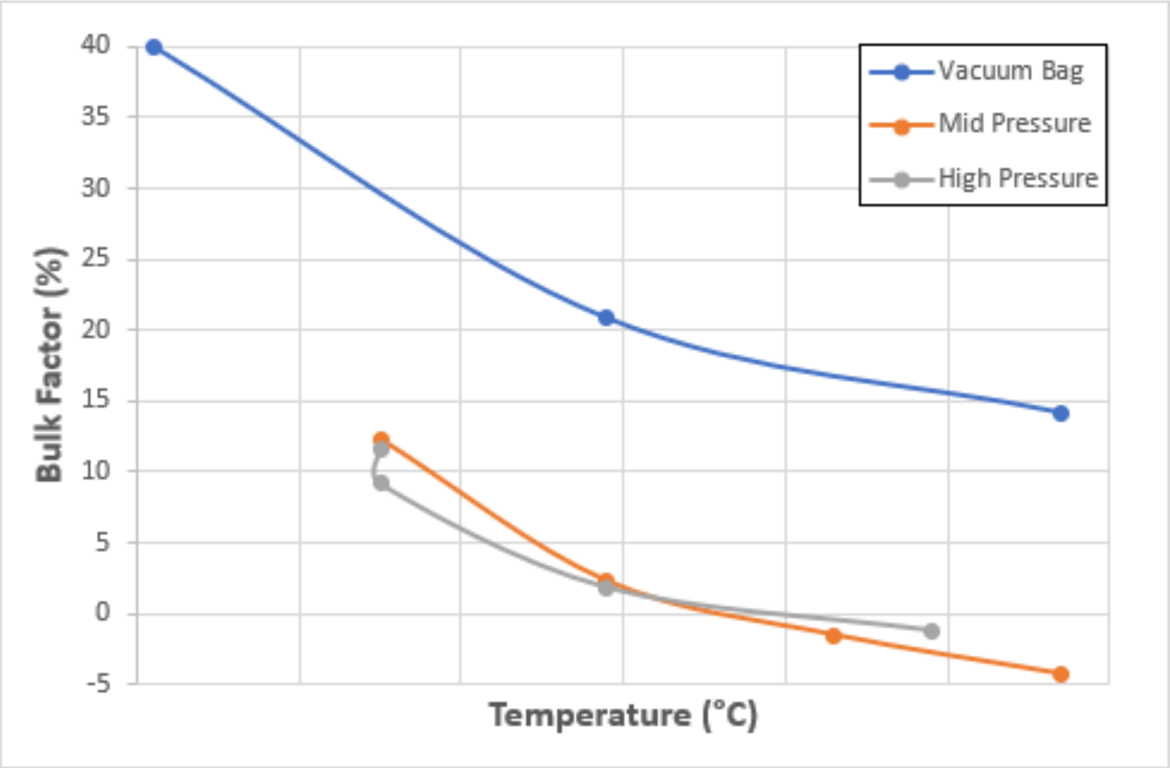
Approved for Public Release; NG24-0740

Compaction Trials Results

- Resulting BF% depends upon temperature and pressure
  - Temperature and pressure parameters must be optimized for each NCF
  - Temperature has a greater impact on BF% than pressure



Consolidation Trials on Quad NCF Preforms: Constant Pressures, Varying Temperatures

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ASF Adaptation for NCF

- Process parameters, developed from flat panel compaction trials, implemented into the ASF process for NCF materials
  - Omega, T, C, and Z cross-sections demonstrated with ASF
    - 1 meter up to 17 meters long stringers
    - Sections of c

ASF Progressive Forming of an NCF Omega Stringer

T-Stringer Preforming Trials

- ASF formed T-Stringer Preforms
  - Constant cross-section
  - 0.6 meters (2ft) long
  - Near-net thickness achieved on numerous preforms
    - -2% BF to +2% BF
  - Stable preforms
    - No measurable amount of deconsolidation observed over time

T-Stringer Preform Made from Quad NCF

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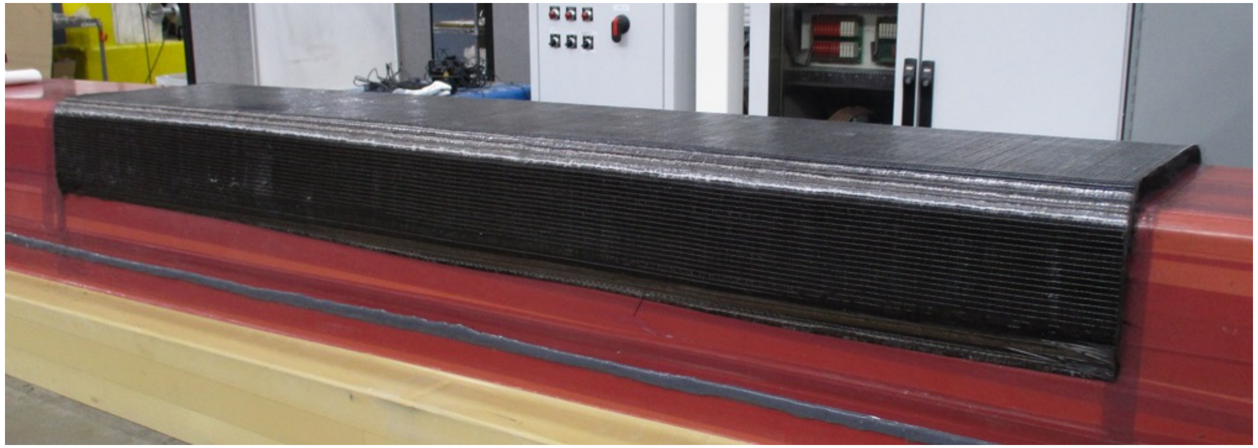
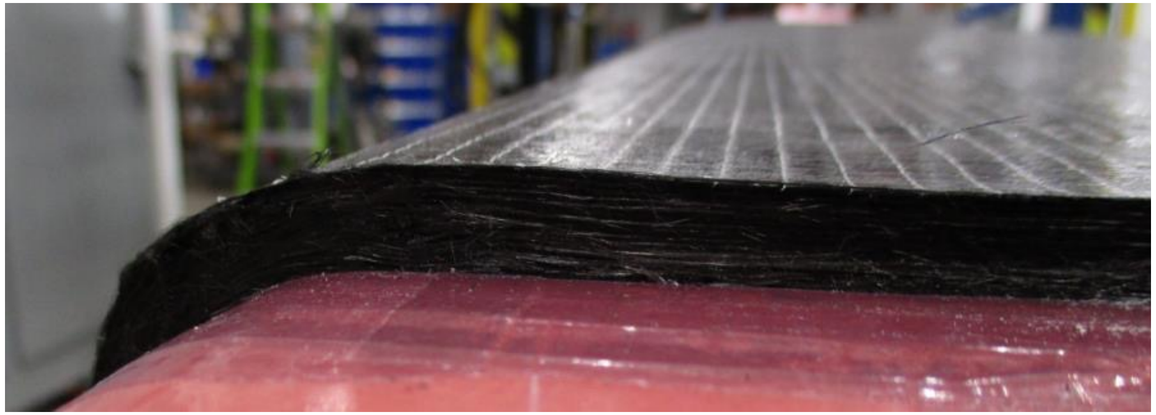
C-Spar Preforming Trials

- ASF formed C-Spar Preforms
  - Variable cross-section
    - Ply drops along the length
    - 18mm (0.7in) thick tapers to 8mm (0.3in)
  - 1.5 meters (5ft) long
  - Near-net thickness achieved
    - 0.25% BF
  - Saertex, Hexcel, and Teijin NCFs formed



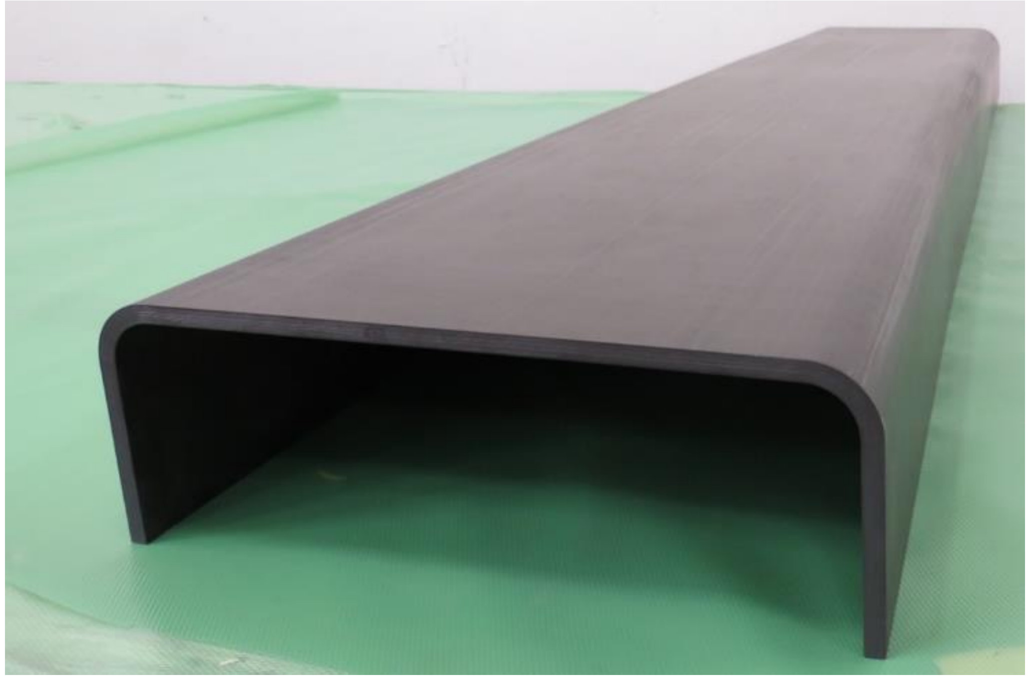
Teijin Biax NCF – Impressive Part Finish and Forming Quality on a Thick Spar Laminate



C-Spar Laminate Compacted to Net Thickness of 8 mm

C-Spar Preforms and RTM Infusion

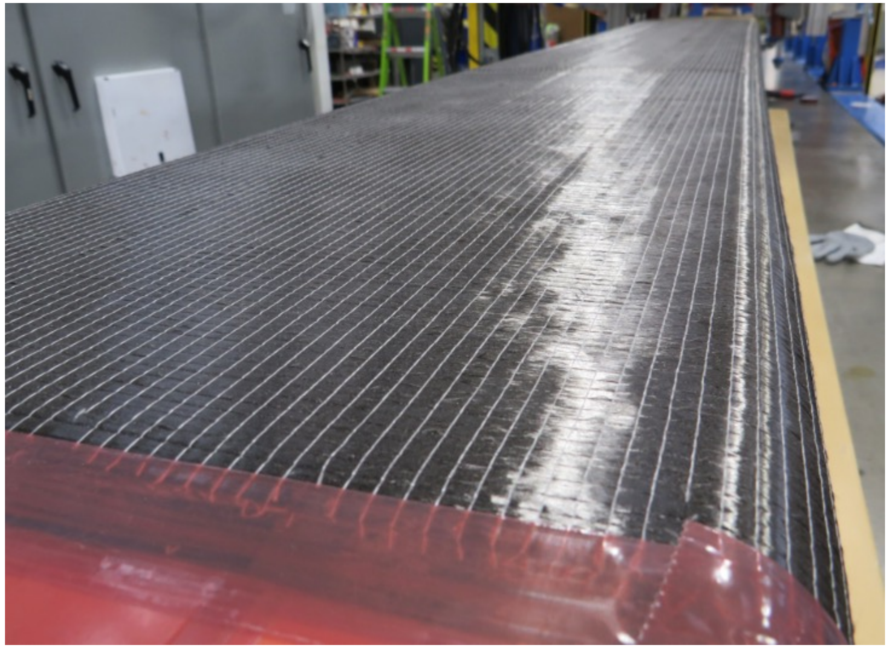
- High-quality, consolidated preforms are a key enabling technology for net-shape RTM processes
  - Preform quality drives final part quality
  - BF% must be tightly controlled
  - Ideal BF% for RTM: 0% to 5%
  - 3 ASF C-Spar Preforms infused (RTM) to validate preform quality and ASF process



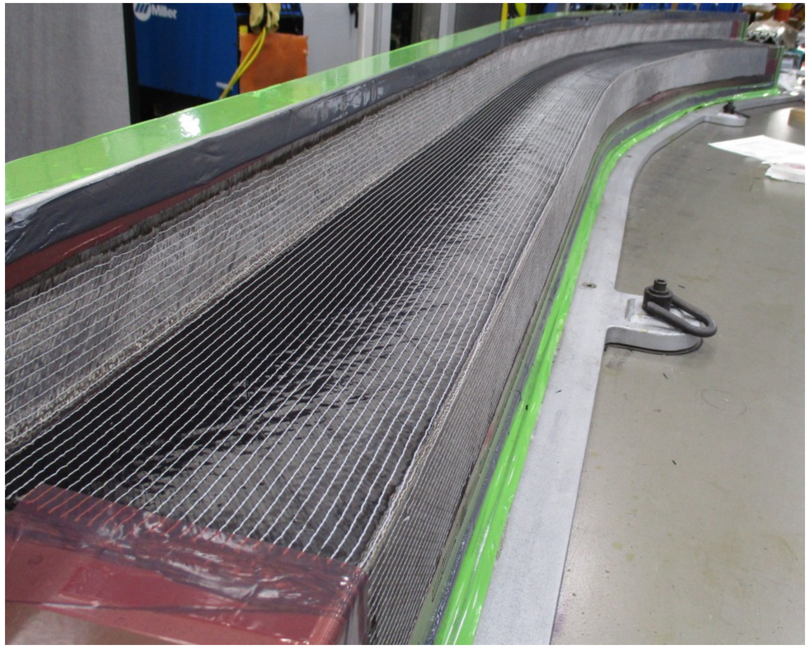
C-Spar Demonstrator Part: The Preform was Manufactured with ASF then Infused in a Closed Mold (RTM)

Observations: NCF and ASF

- NCF Format: Biax & Triax
  - Biaxial NCFs performed well with ASF
  - Triaxial NCF (+45/90/-45) formed successfully on curved frame geometry



Teijin Biax NCF Showing Excellent Conformance to the Radius



Saertex Triaxial NCF Formed on a Curved Z Geometry

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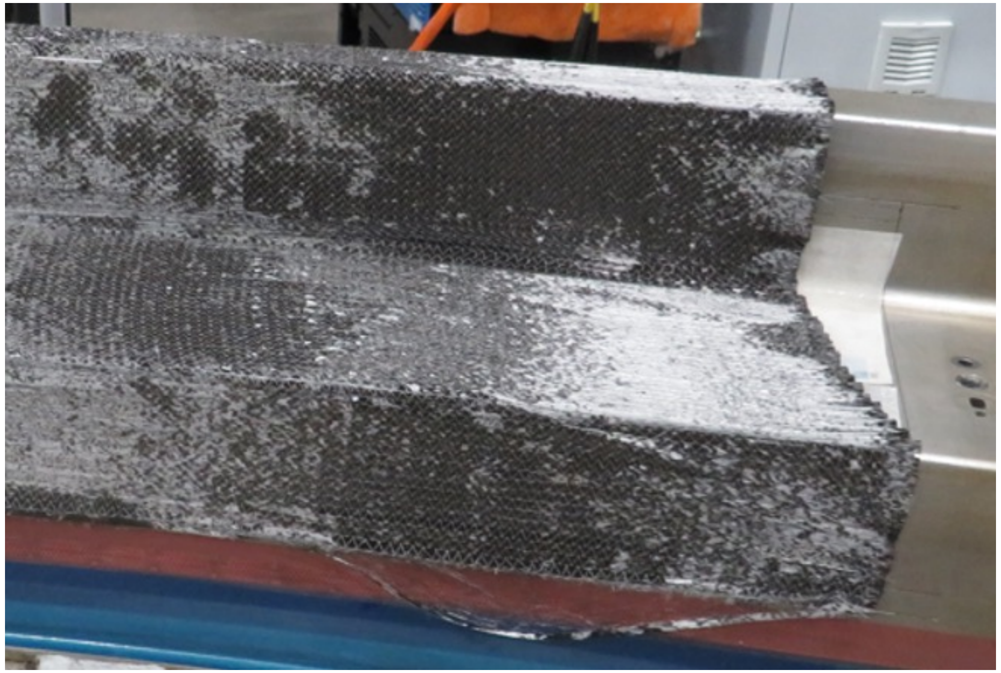
Observations: NCF and ASF

- NCF Format: UD & Quad
  - Careful processing required for quad axial NCFs
  - Some UD NCF construction allows significant tow shearing



Saertex UD - 240gsm, Tow Shearing and Compliance to a Curved Frame Geometry

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Observations: NCF and ASF

- NCF Constituents: Stitching, Veil, and Binder
  - Melt temperatures of the stitching and veil drive the ASF process
    - Ideal for ASF: veil melt temp < stitching melt temp
  - Robust stitching is preferred over fine stitching
  - NCFs with powder binder perform well with ASF process
    - Lower processing temperatures required
    - NCF plies can be re-worked without damaging laminate

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Conclusions

- Automated Stiffener Forming (ASF) technology has been demonstrated to manufacture high-quality stiffener preforms for primary aircraft structures
  - – Controlled heat and compaction for optimal BF%
  - – Wrinkle-free laminates
  - – Successful RTM infusions validate the ASF process

Questions?