MANUFACTURE OF COMPOSITE TUBE SPAR WING ASSEMBLY MANUFACTURING DEMONSTRATION UNITS WITH MATRIX REFLOW JOINTS

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About Me:

- Richard Larson
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- Structural Mechanics and Concepts Branch at NASA Langley Research Center
- Composite material researcher
  - Structural analysis; progressive failure analysis; composite manufacturing; bonded and bolted joints; machine learning; deployable structures

Outline

- Background
- AERoBOND+
- Structural Wing Experiment Evaluating Truss-bracing 15 ft (SWEET-15) test article and AERoBOND+ manufacturing demonstration units
- Manufacturing processes
- Manufacturing demonstration unit (MDU) 1
- MDU 2
- Summary and conclusions

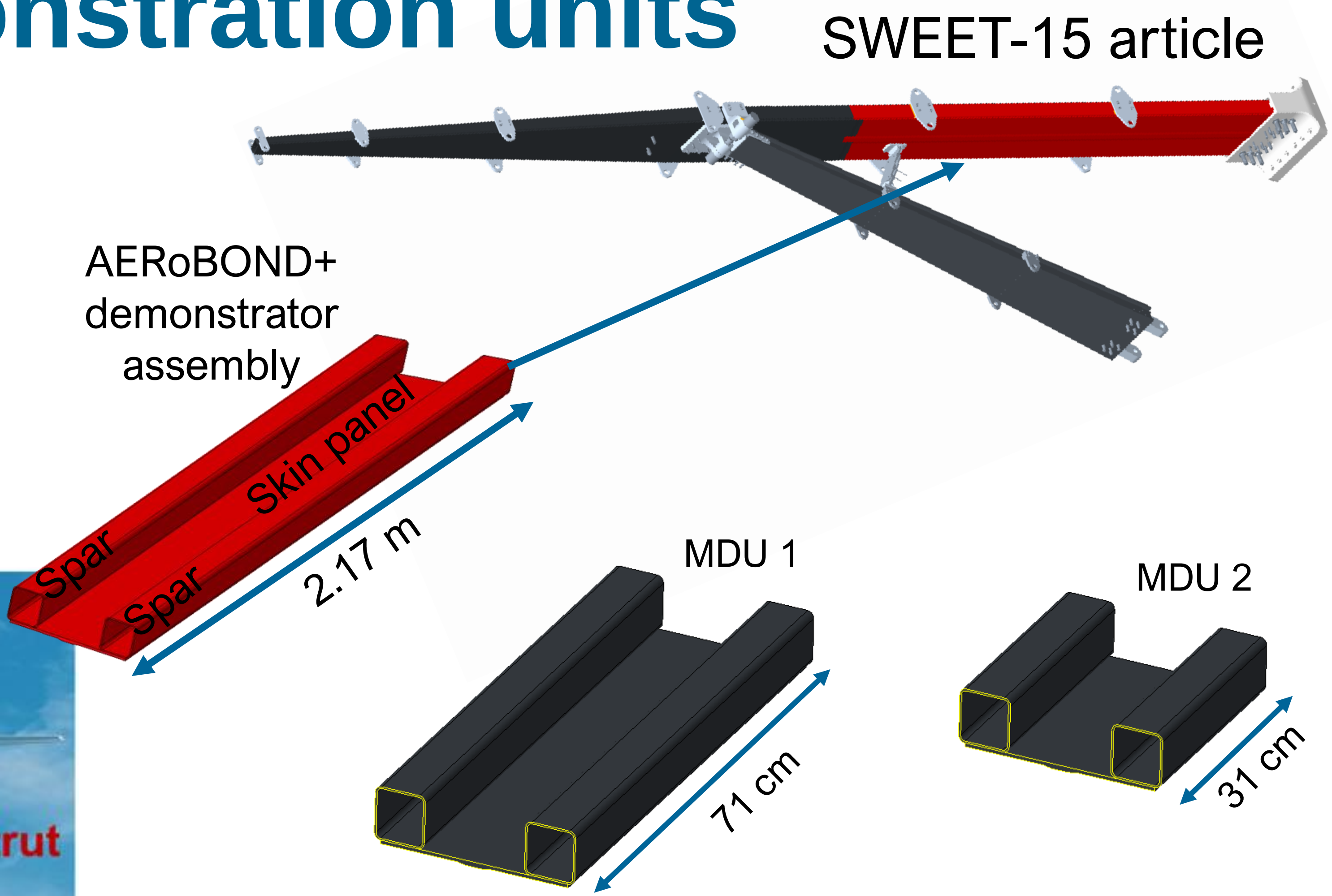
Background

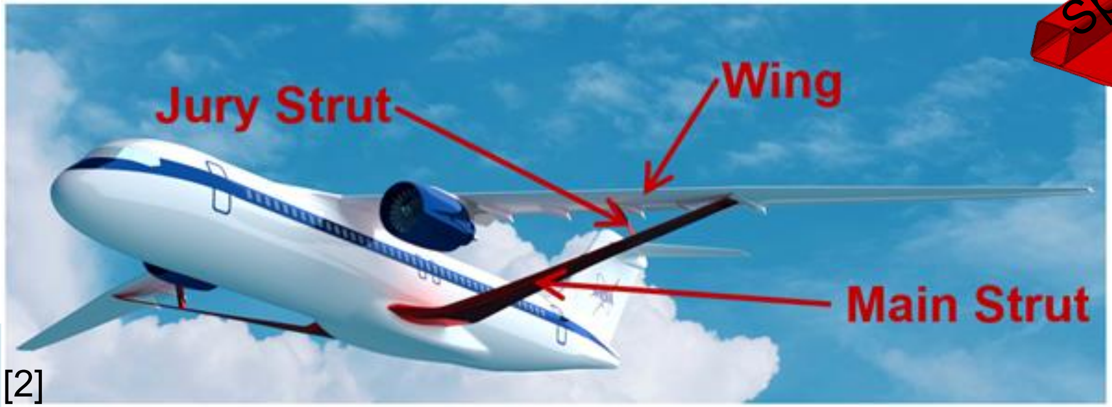
- Adhesively bonded joints offer many advantages over bolted joints:
  - Faster assembly
  - Reduced stress concentration
  - Reduced weight
- Minor contamination can result in weak and unreliable bonds
  - Certifying agencies typically require redundant load path for civil transport aircraft
- AERoBOND
  - Latent cure, offset-stoichiometric matrix-reflow composite bonding
    - Uncured epoxy on mating parts reflows and mixes with added hardener during secondary cure
  - More reliable, higher quality bonding than adhesive
  - AERoBOND+ => hybrid AERoBOND method that also uses FM209 adhesive
    - Offers mechanical improvement over traditional adhesive bond [1]

[1] - Hudson et. al, “Offset-stoichiometric reflowable composite bonding method with adhesive for mitigating strict faying surface tolerances”, Composite Structures, Vol 351, Jan 2025

Test article and manufacturing demonstration units

- NASA Advanced Air Transport Technology project
  - SWEET-15
  - AERoBOND+ is candidate for technology demonstration





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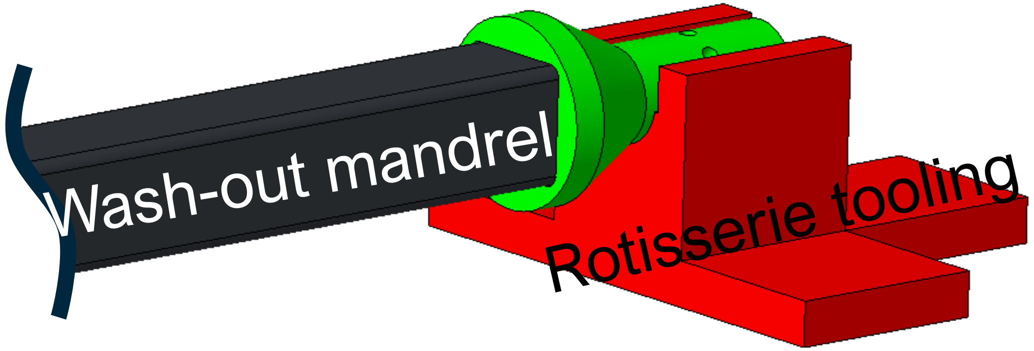
[2] - Gipson, L., “NASA Plans for Subsonic Flight Demonstrator,” https://www.nasa.gov/aeroresearch/nasa-plans-for-subsonic-flight-demonstrator, NASA, April 24, 2023.

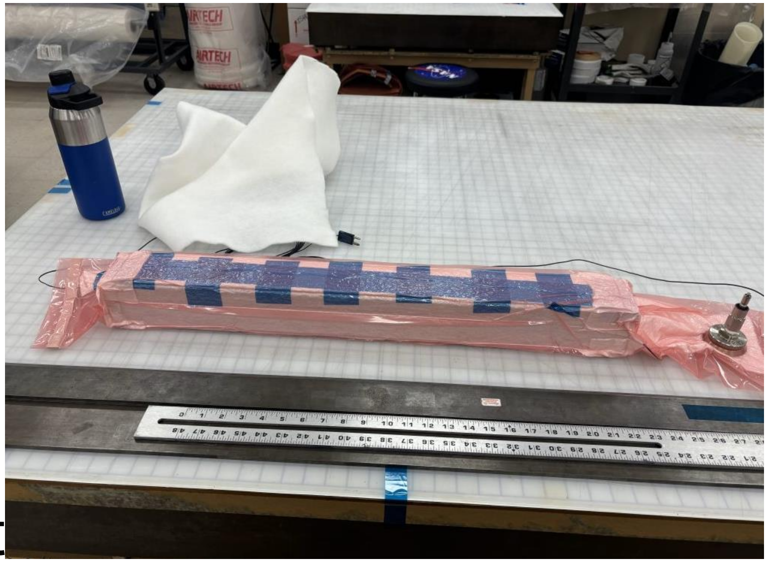
Manufacturing process – spars

- Wash-out tooling technique was used
  - Spar laid up on and bagged to wash-out tooling
  - Tooling removed post-cure with pressurized water
- Single 71-cm-long spar produced
- $[0°/45°/90°/-45°]_{2s}$ layup of unidirectional IM7-8552



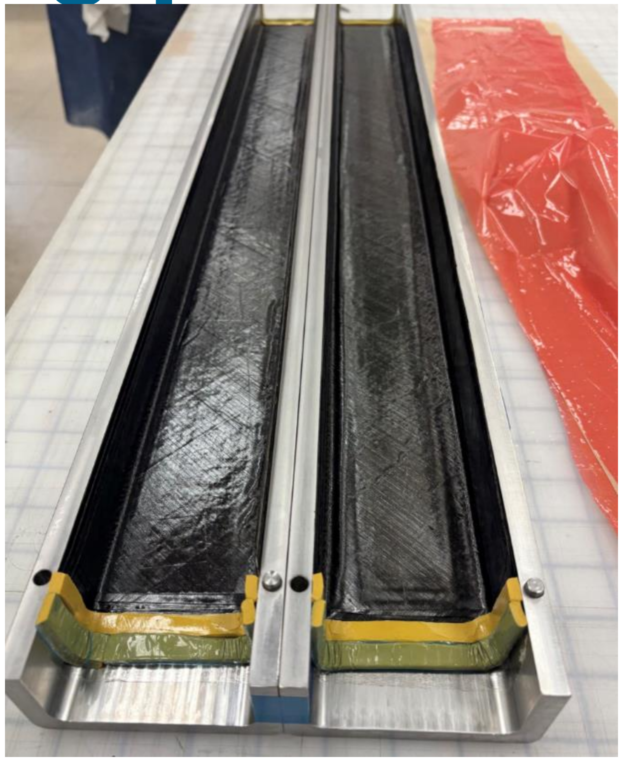
Cured spar

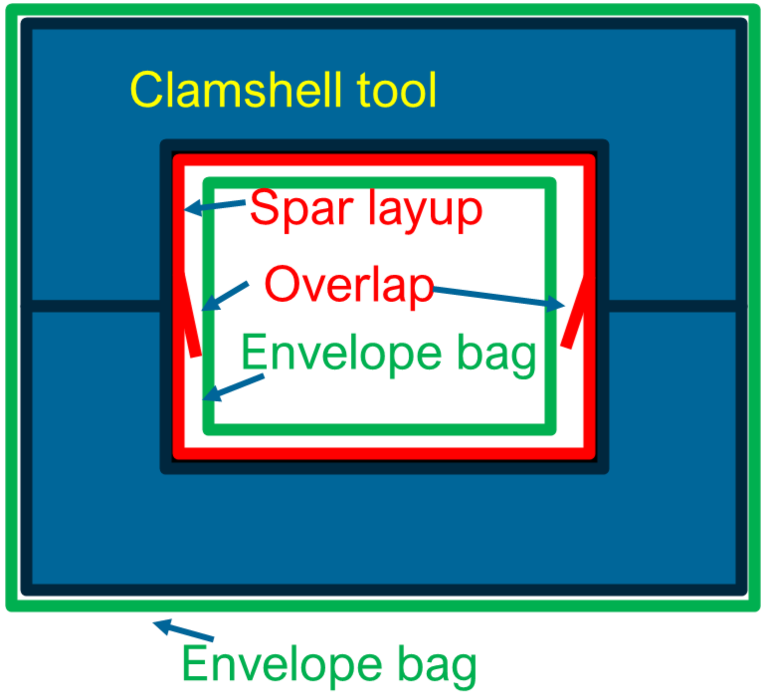
Wash-out tool



Manufacturing process – spars

- Two separate spars were made with a clamshell-tooling process
- The layup of the first spar used the Hexcel® IM7-8552 plain weave material, following the $[0°/90°, \pm45°]_{4s}$ layup schedule
- The layup of the second spar used the IM7-8552 unidirectional material, following a $[0°/45°/90°/-45°]_{2s}$ layup schedule
- Both spars were 71 cm in length
- The plain weave layup spar was cut into two 31-cm lengths and used for the second MDU



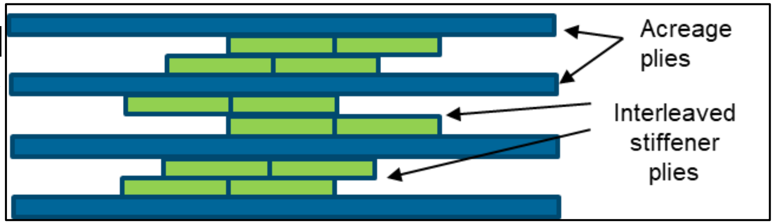


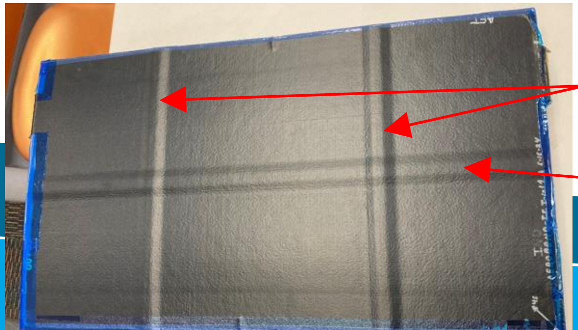
Manufacturing process – skin panel

- An integrally stiffened (IS) skin panel was laid up on the Integrated Structural Assembly for Advanced Composites (ISAAC) robot at Langley Research Center
- The panel had the layup of $[[90°/(90°/0°)_2/0°/(90°/0°)_2/-45°/(90°/0°)_2/45°/(90°/0°)_2]_2]_s$ where the $(90°/0°)_2$ groupings are IS plies only, and do not cover the entire panel acreage.
- Each IS ply is shifted 1/8” from the previous IS ply in a repeating pattern of left, center, right.

Non-staggered plies

Staggered plies



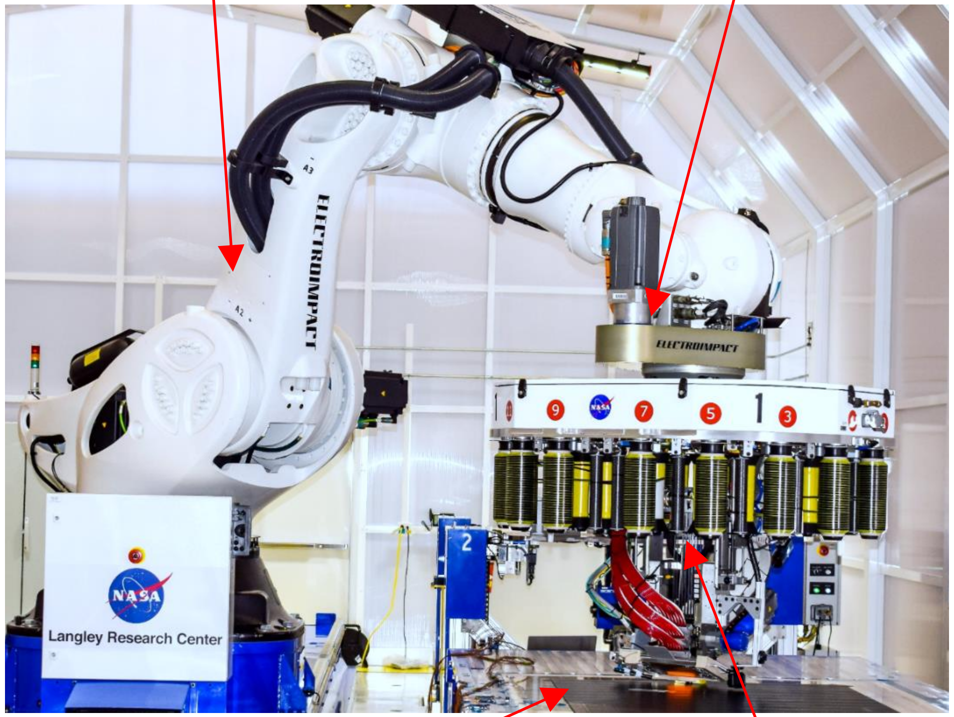


90° integral stiffeners

0° integral stiffener

ISAAC robot

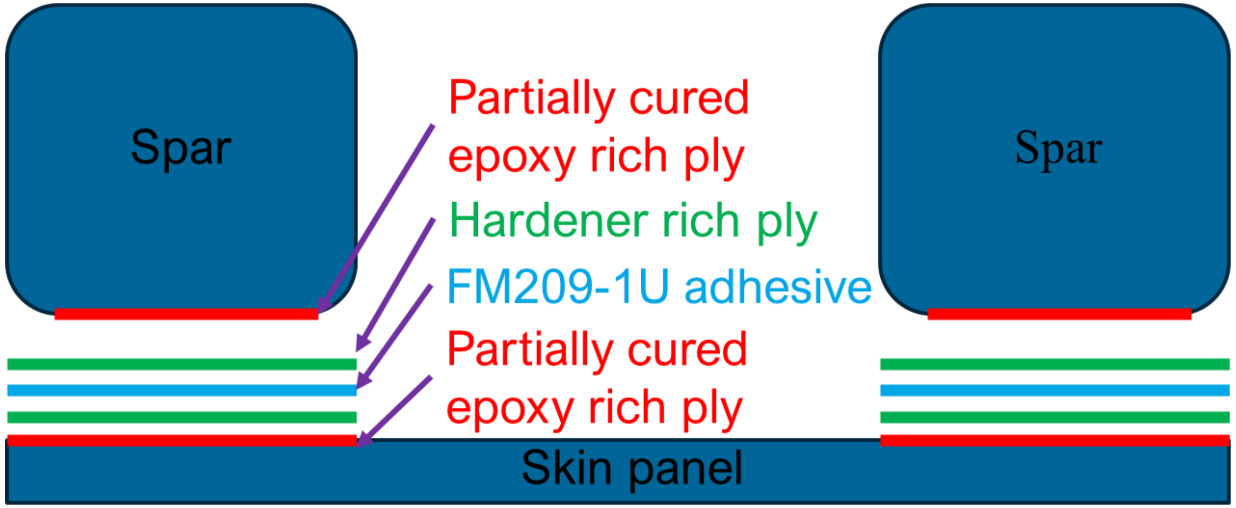
Automated fiber placement head

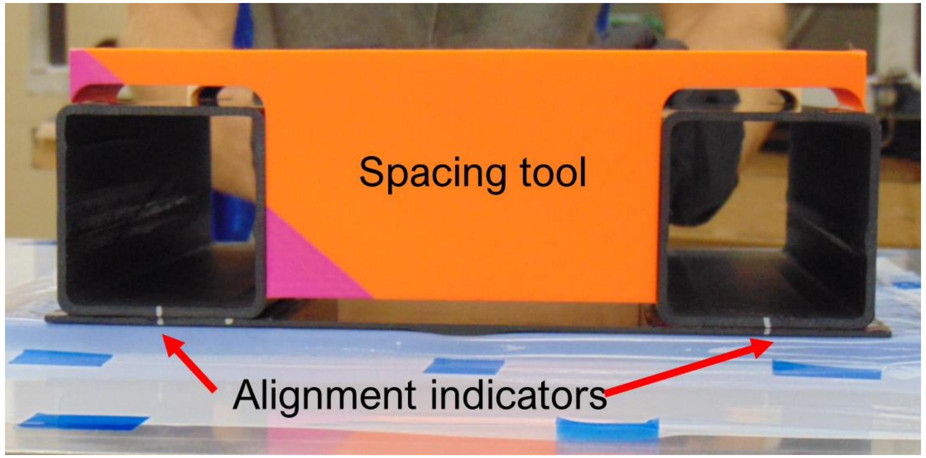


Layup surface

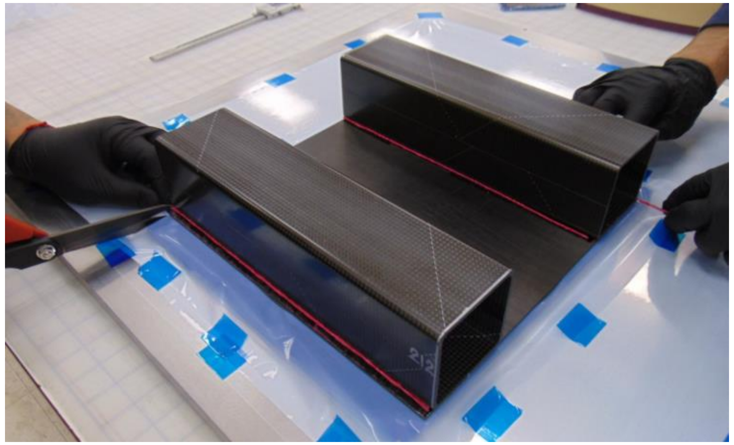
Prepreg spools

Manufacturing process – AERoBOND+



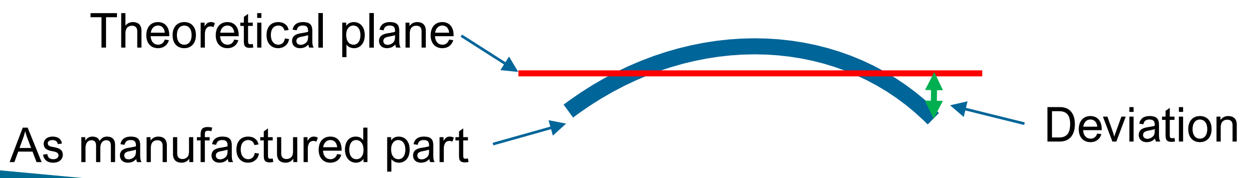


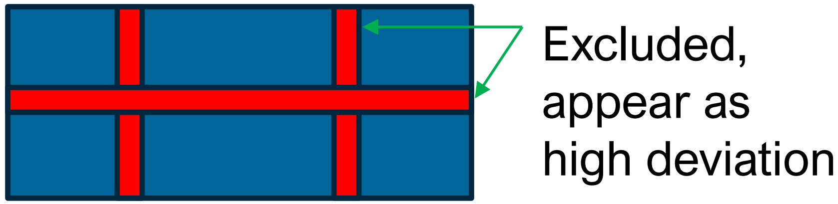
- Each spar and skin panel had an additional ply not accounted for in the regular layup schedule
  - Epoxy-rich (ER) ply placed on the faying surface of each sub-component
  - This ply is only partially cured during the sub-components cure cycle
- Prior to the second cure cycle, a stack two hardener rich (HR) plies with FM209-1U adhesive in between was placed at the faying surface between the subcomponents
  - The additional hardener reacts with the un-reacted epoxy during the secondary cure



Evaluation of manufacturing demonstration units

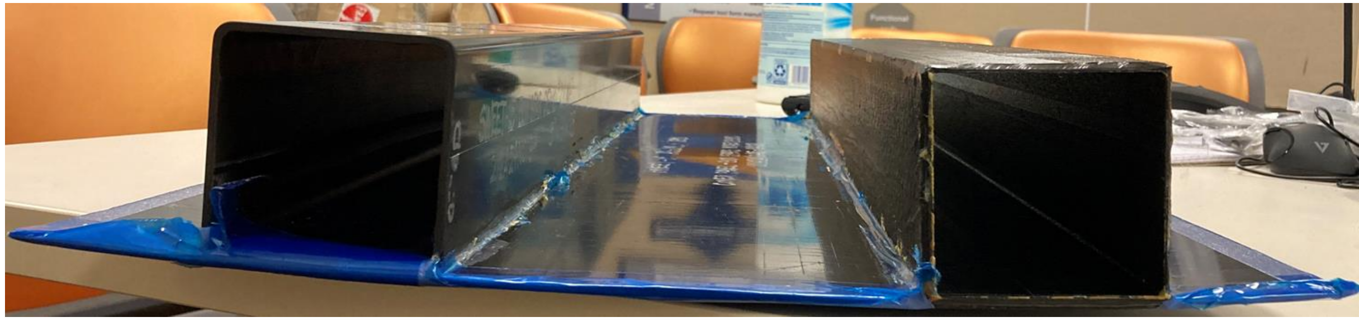
- Design geometric deviation was evaluated using a portable coordinate measurement machine (PCMM) with 3D scanner attachment
  - Used to create 3D map of skin panel surface of each assembly
  - To assess flatness, selected surface area used to calculate theoretical plane based on root-mean-square (RMS) values.
  - This plane served as a baseline for a 3D comparison image, providing statistical values and visual representation of deviation
  - Plane was defined based on panel surface but excluded IS surfaces

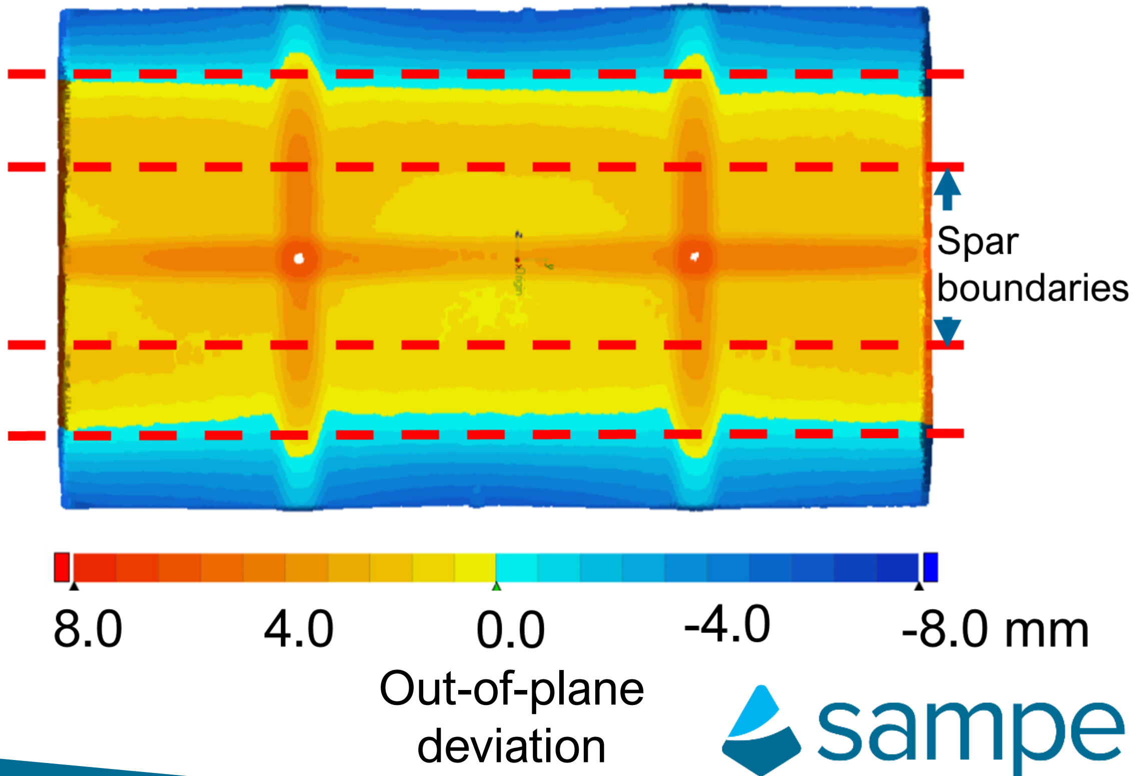


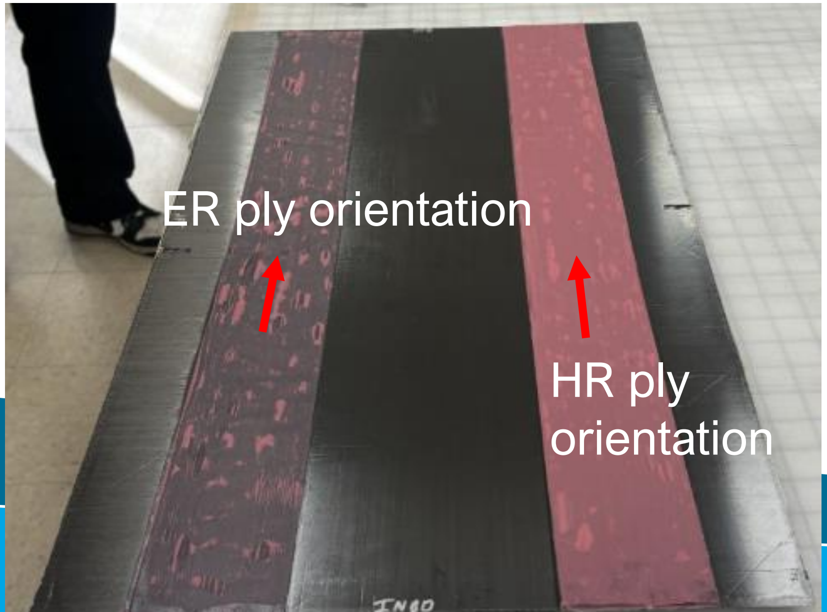


MDU 1

- ER and HR plies in same orientation
- Envelope bag around entire part
- Part dimensions 71 cm x 41 cm with 6-cm overhang past spar edges
- Up to 8 mm out-of-plane deviation observed







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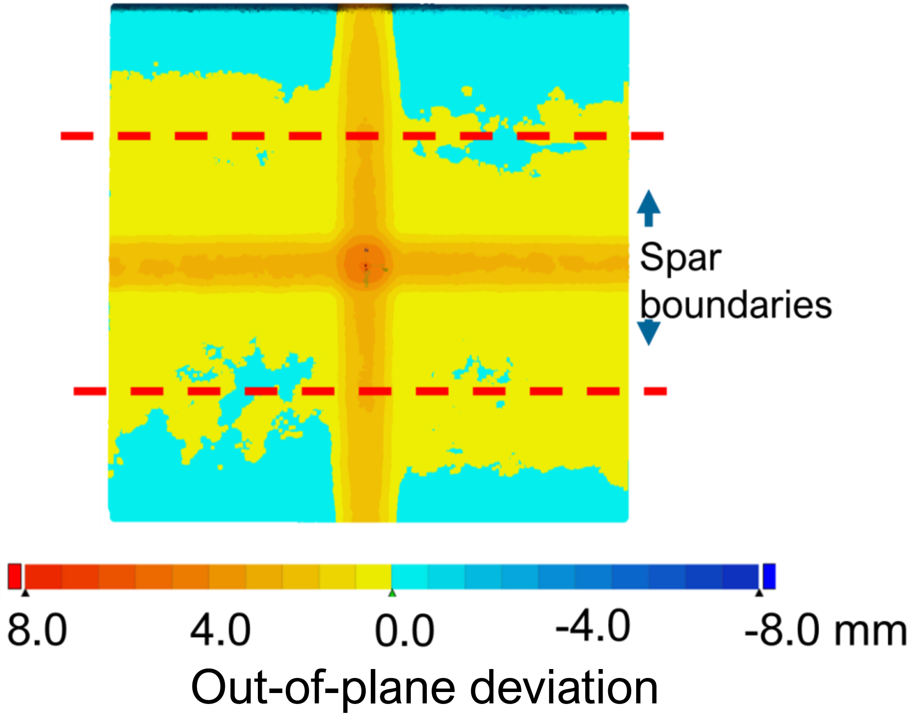
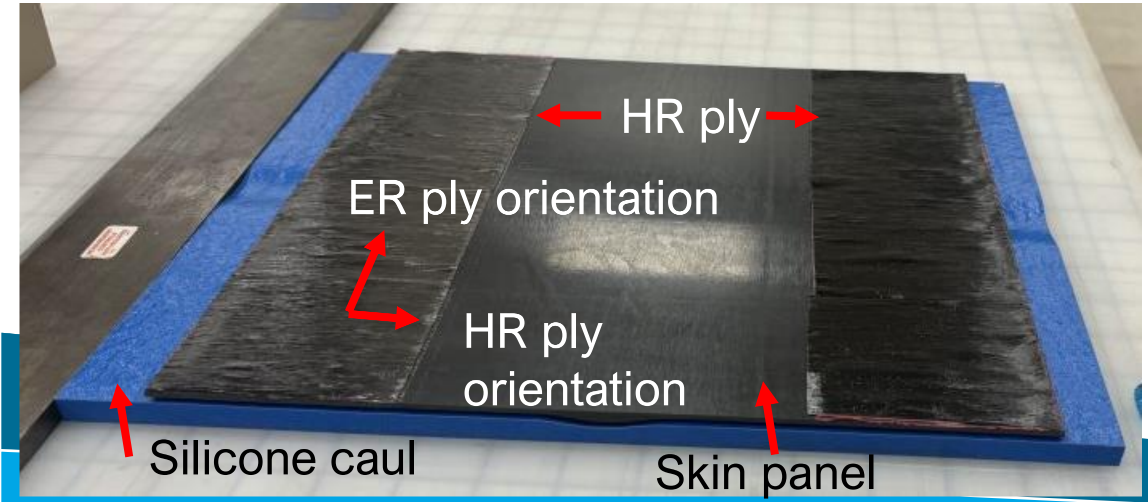
MDU 2

- Part bagged to tool
  - Pressure will keep part flat during secondary cure
- HR plies placed orthogonal to ER plies
  - Coefficient of thermal expansion (CTE) of fibers lower than matrix; this orientation may reduce warpage
- Part dimensions 31 cm x 31 cm without overhang past spar edges
- Up to 0.8 mm out-of-plane deviation observed





Summary and conclusions

- Two manufacturing demonstration units were used to evaluate feasibility of AERoBOND+ use on SWEET-15 sub-scale truss-braced wing test article
- Lessons learned from first MDU were incorporated into second MDU
  - Alternate bagging scheme and HR ply orientation resulted in successful second manufacturing demonstration
- Envelope bag may have caused warpage in MDU 1 due to lack of pressure on skin panel overhang region and part being near glass transition temp during cure of HR plies and matrix reflow
  - Allowed shape of part to change during secondary cure
- Difference in CTE between fiber and transverse directions may have been responsible for deviations in MDU 1
  - AERoBOND+ material properties were determined when ER and HR plies were co-directional; could be reduced when plies are orthogonal
    - Fibers may not nest together the same when orthogonal

Ancillary lessons learned

- Washout tooling should be removed prior to secondary cure for easier sub-component inspection
- HR ply, adhesive, HR ply stack is better placed all onto one component when joining the mating components, instead of putting half on each mating component
- It was easier to place the ER plies on top of the skin panel after the panel was laid up, instead of trying to do AFP layup on top of the ER plies
  - The ER plies were extra tacky and had tendency to get dragged by AFP head

Acknowledgements

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    - Manufacturing Applications Branch
    - Structural Mechanics and Concepts Branch
    - Materials and Structures Experiments Branch
    - ISAAC team

Questions?

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