Finite Element Analysis Validation for Stitched, Blade-Stiffened Aerospace Structures

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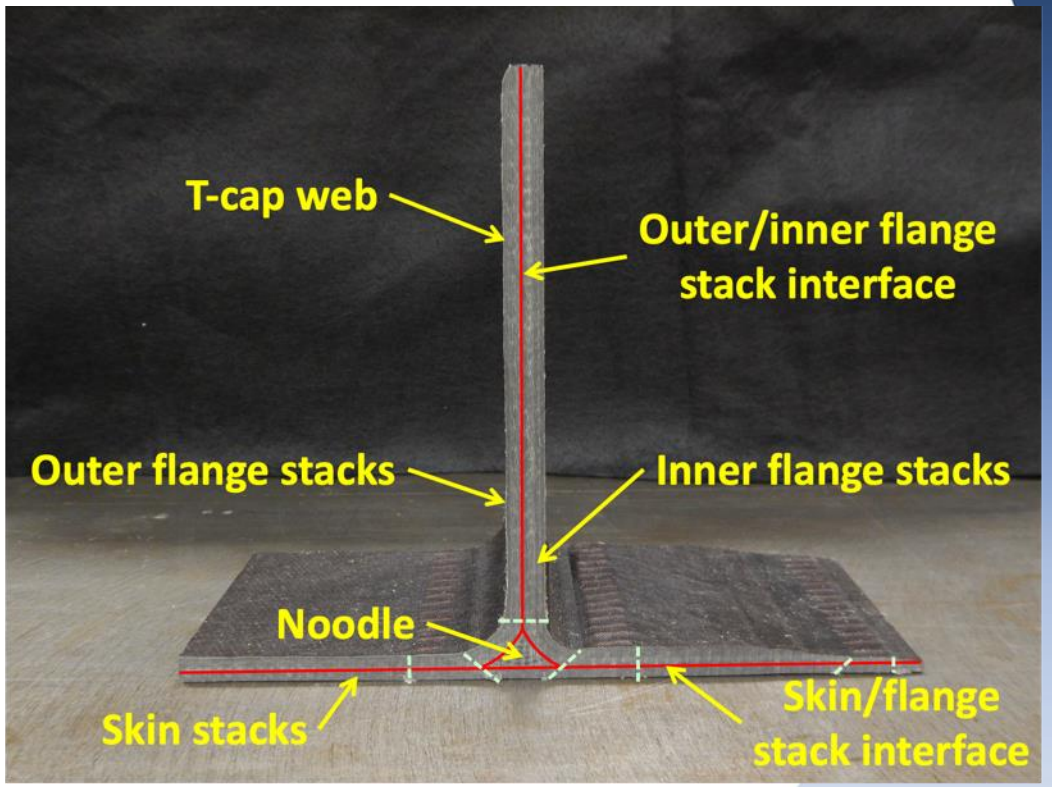
AIAA SciTech Forum
January 3-7, 2022
San Diego, California

Background

- **Stitched composite test articles tested at NASA Langley Research Center (LaRC) have demonstrated performance benefits**
- **Continued interest in stitched composites at NASA and elsewhere require better analysis capabilities to perform design and analysis**
  - Hi-rate Composite Aircraft Manufacturing (HiCAM) project: increase manufacturing rate
- **Analyses of models are often performed using simplified approaches for sizing and design**



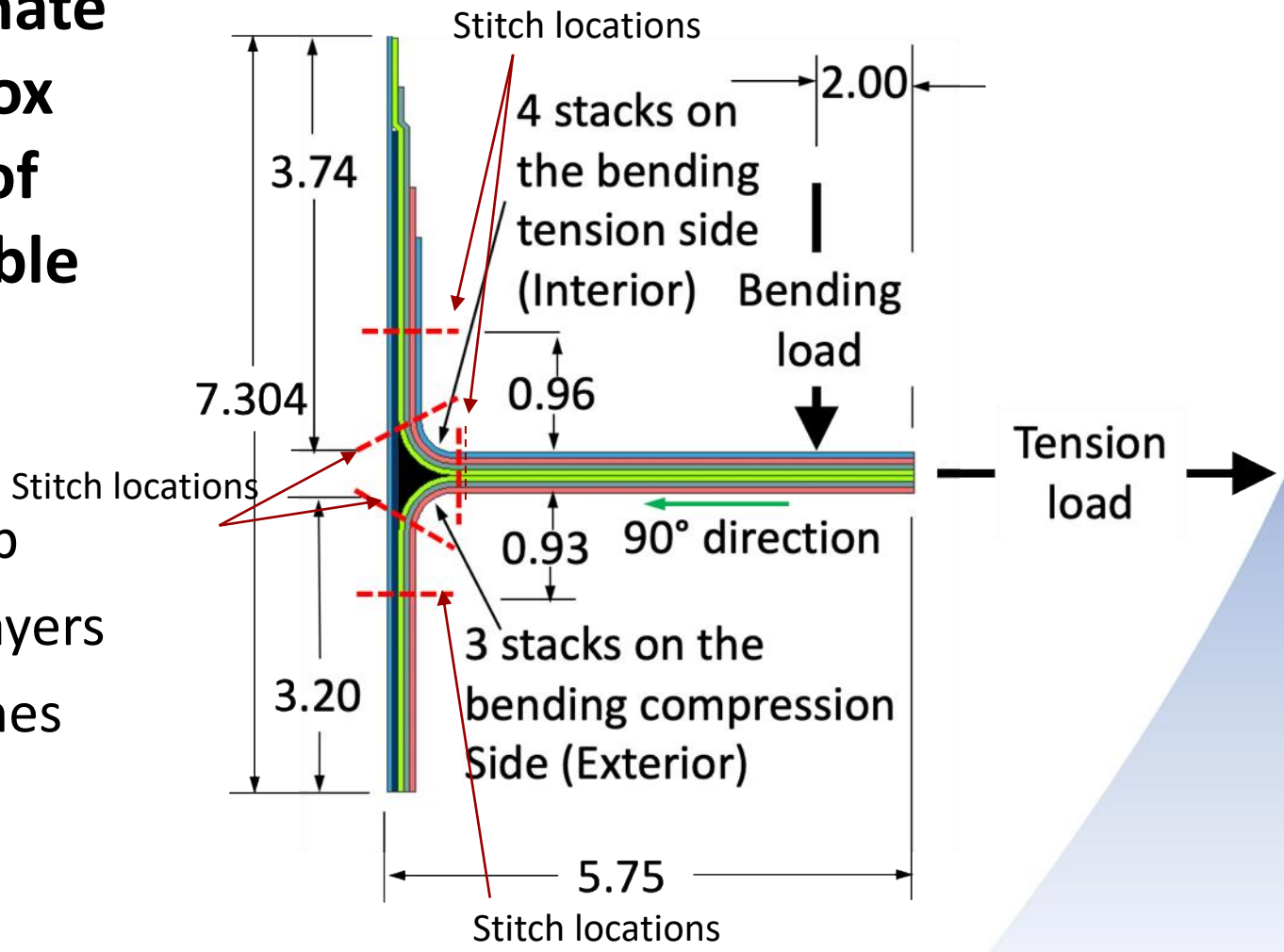
Objective

- Explore the use of 2-dimensional (2-D) and 3-dimensional (3-D) finite element model approaches for non-stitched and stitched T-cap structures undergoing tension or bending loads to develop possible design and analysis methods for stitched composites

- Compare the results from these models to existing digital image correlation (DIC) surface strain data with the goal of strains matching within ~25%

Test Specimens

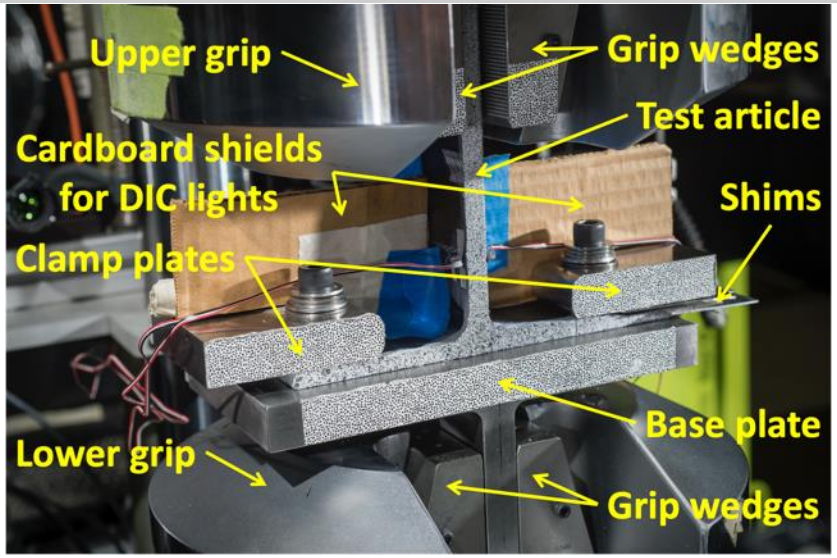
- **T-caps were cut from an alternate keel panel for the multi-bay box test article fabricated as part of the Environmentally Responsible Aviation (ERA) project**
- **Web and skin stacks:**
  - [+45, -45, 0, 90, 0, -45, +45] layup
  - Equivalent to 11 unidirectional layers
  - Stitches located at dashed red lines (indicated by red arrows)
- **Stitches are Vectran$^{\phi}$ thread**



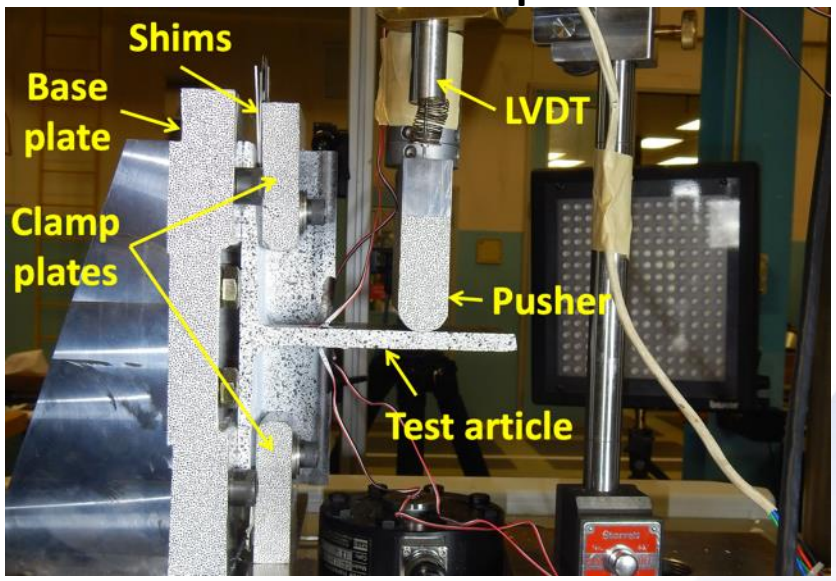
$^{\phi}$ The mention of a company or product is not an endorsement by NASA.

Test Setup

- **T-Cap specimens were tested to failure under separate tension and bending loads**
- **Load introduction was monitored with strain gauges on blade surfaces**
  - Back-to-back pairs on each edge of specimen
- **DIC photogrammetry was used to capture cross-section strains on surface**



Tension setup

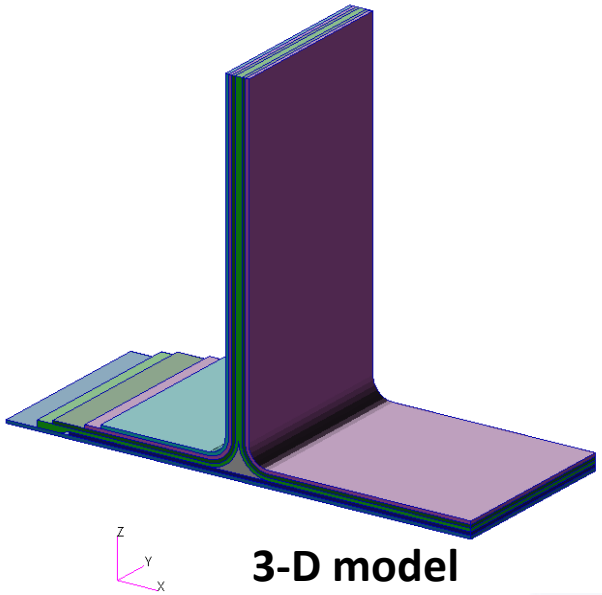


Bending setup

Finite Element Modeling

- **2-D and 3-D finite element models were developed**
  - 2-D model of cross-section with shell elements
    - Shell thickness equal to stitch spacing
    - For use in preliminary design
  - 3-D model of test specimen
    - For use in intermediate design analysis
  - Both stitched and non-stitched models analyzed
- **All models were compared to stitched test specimen DIC strain data**
  - Surface strain contours

2-D model



3-D model

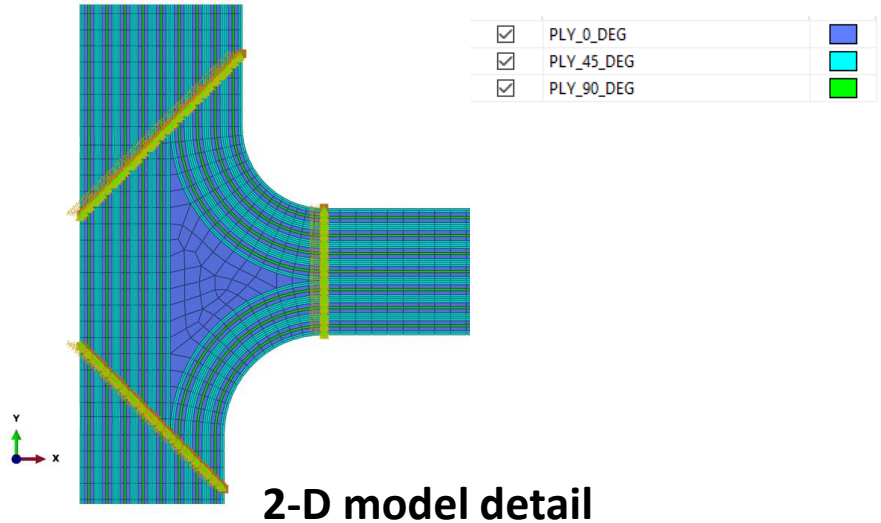
Finite Element Modeling: 2-D Model

2-D plane strain model

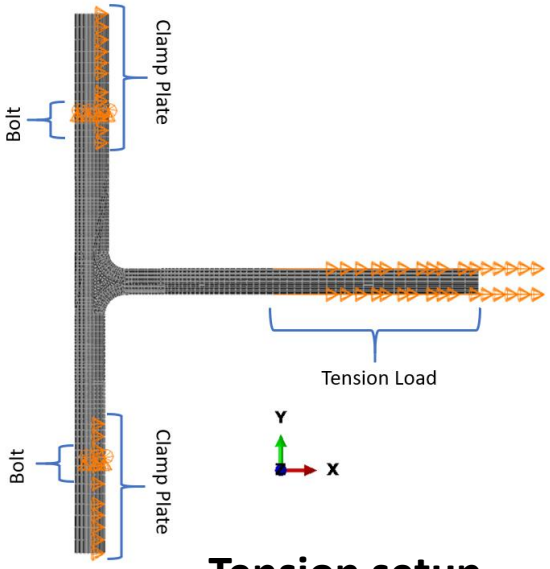
- S4R and S3R 2-dimensional 4-noded quadrilateral and 3-noded triangular elements
- Individual plies modeled
- 2-D connector elements for stitches with axial Vectran thread properties

Boundary conditions defined to match test setup conditions

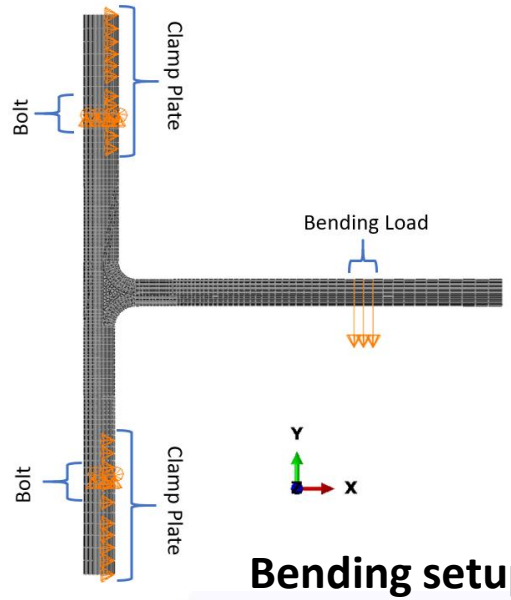
- Zero-displacement enforced out of plane; not shown here for clarity



2-D model detail



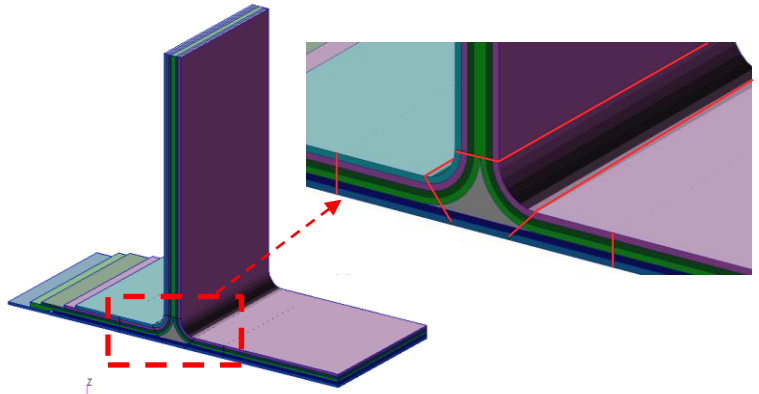
Tension setup



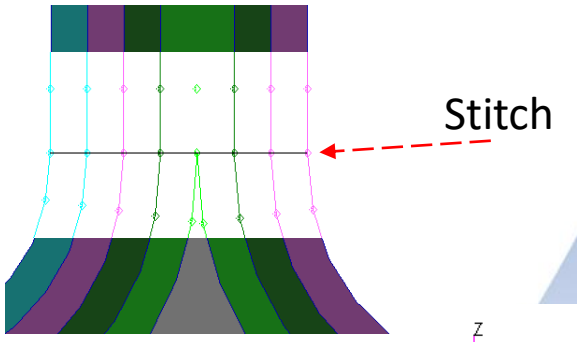
Bending setup

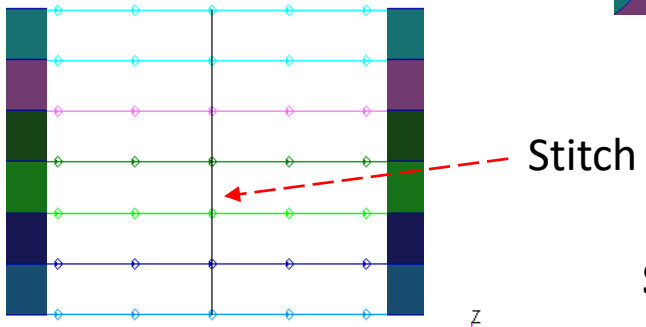
Finite Element Modeling: 3-D Model

- **3-D model**
  - SC8R or SC6R continuum elements for plies
  - C3D8 elements for “noodle”
  - 2-noded beam elements stitches
- **One element through the thickness for each stack**
- **Stitch elements created from nodes through the thickness**



3-D model

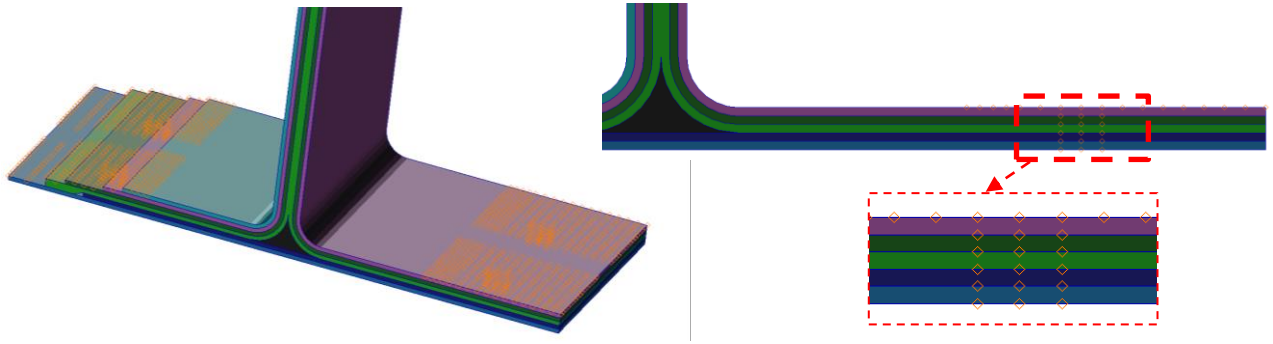




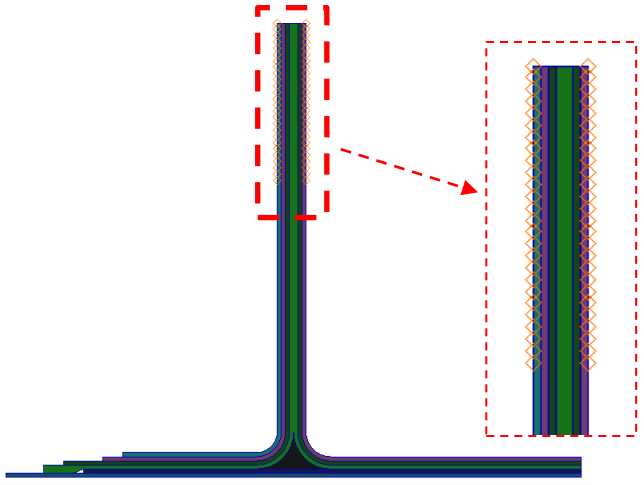
Stitch details

Finite Element Modeling: 3-D Model

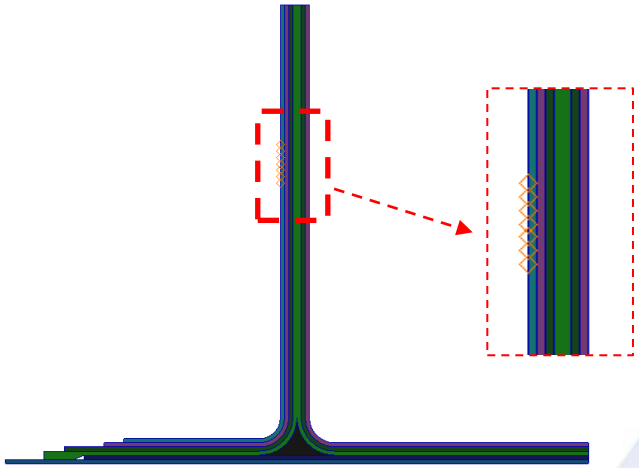
- 3-D model boundary conditions defined by test setup conditions
- Load applied as enforced displacements for each test load case



Bolt and clamp boundary conditions



Tension load application



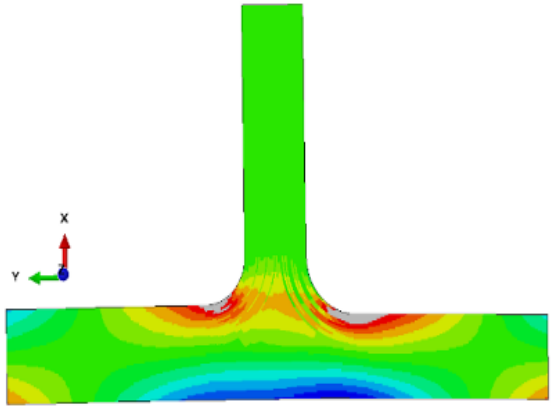
Bending load application

Finite Element Analysis and Results

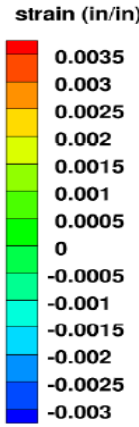
- 2-D and 3-D models analyzed using Abaqus nonlinear analysis
- Results compared at displacements correlating to initial failure displacements in the test
- Resultant load from model boundary conditions is ~325 lb, consistent with tension load case initial failure load recorded in test
- Resultant load from model boundary conditions is ~2300 lb, consistent with bending load case initial failure load recorded in test

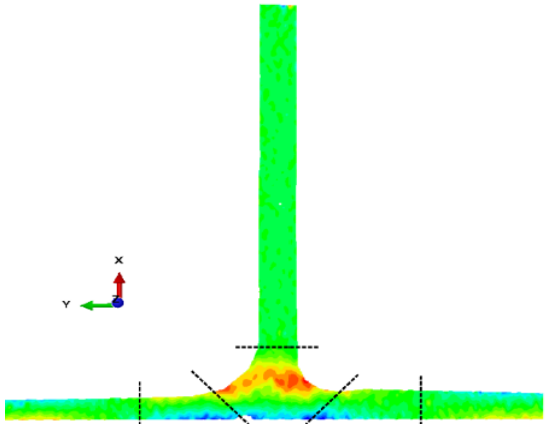
Finite Element Analysis and Results: Non-Stitched Tension

Global X-Direction Tension

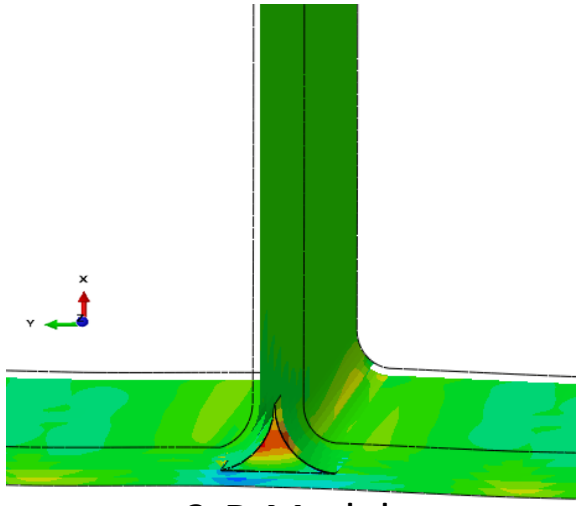


2-D Model



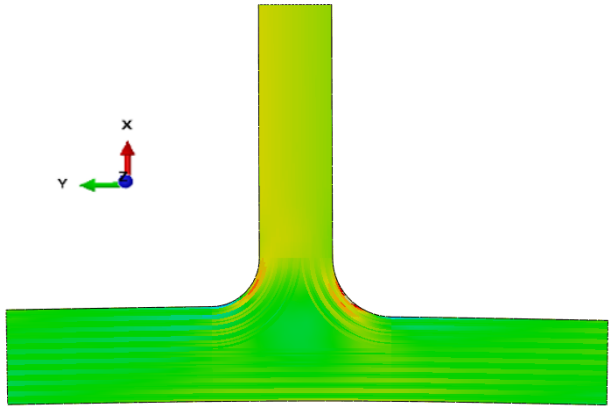


DIC



3-D Model

Global Y-Direction Tension



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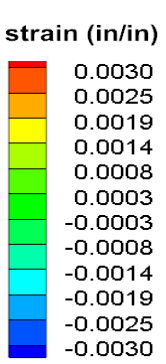

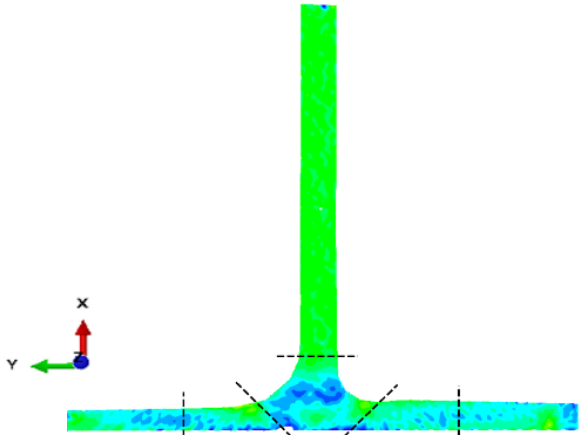

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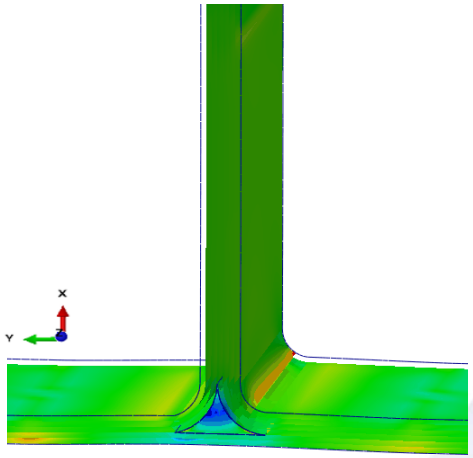
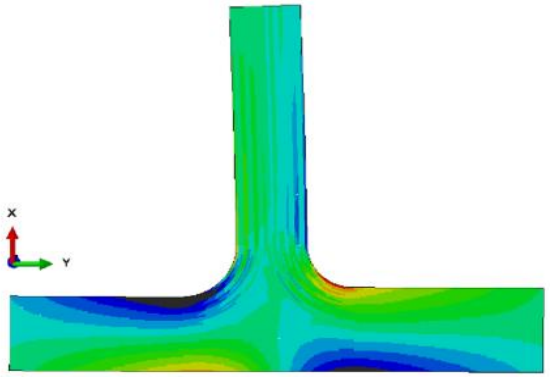


3-D Model

Finite Element Analysis and Results: Non-Stitched Bending

Global X-Direction Bending



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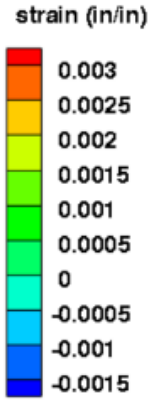

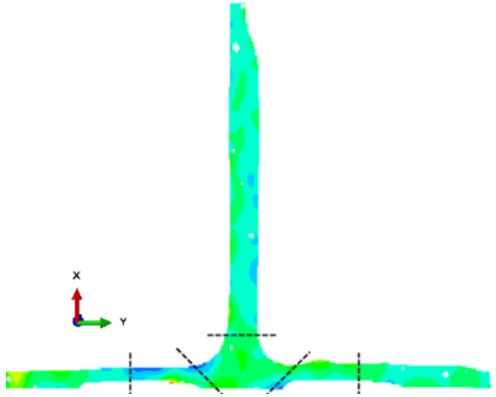

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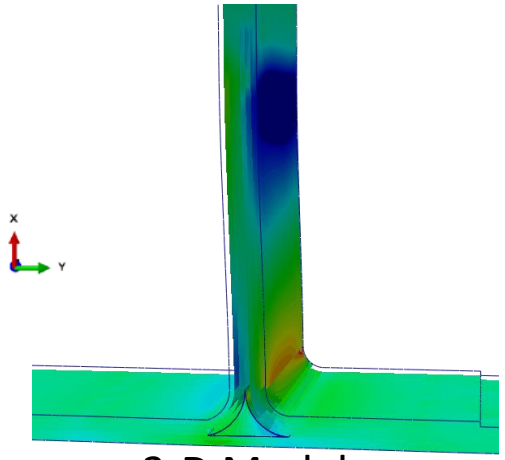
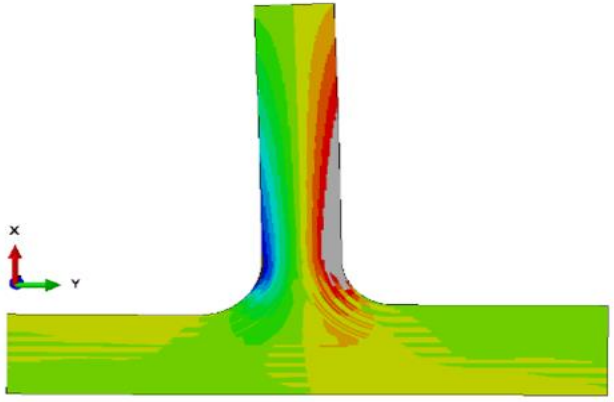


3-D Model

Global Y-Direction Bending



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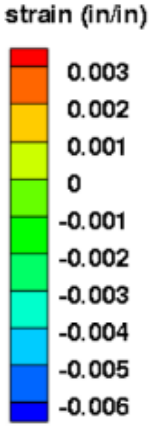

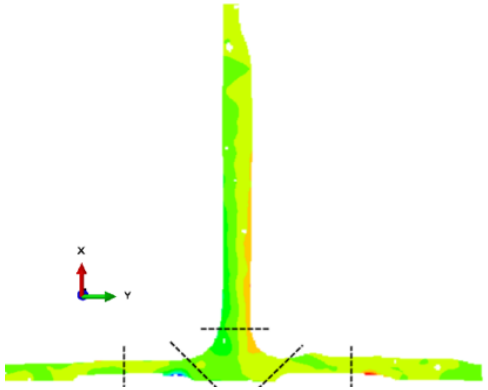

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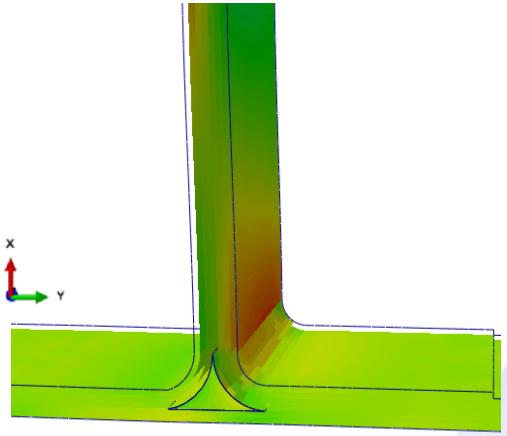
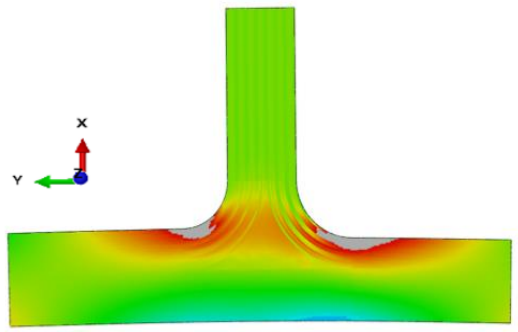


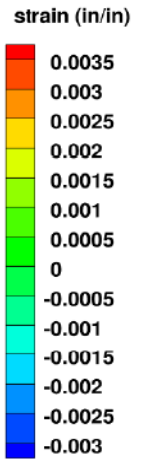
3-D Model

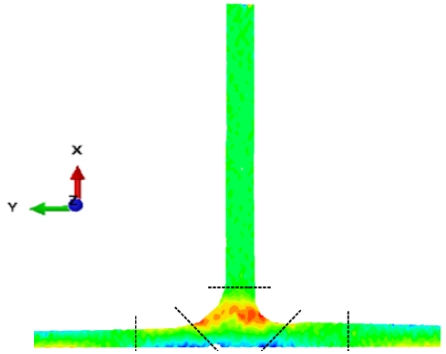
Finite Element Analysis and Results: Stitched Tension

Global X-Direction Tension



2-D Model





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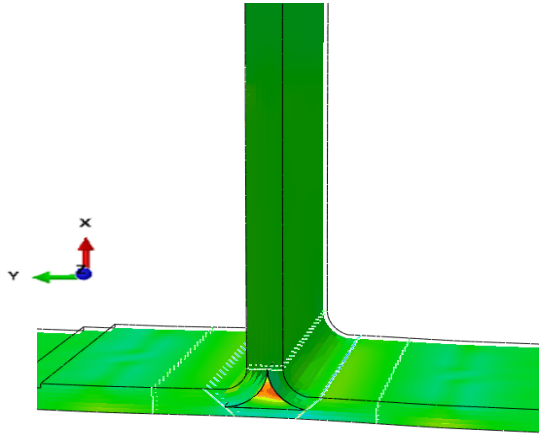
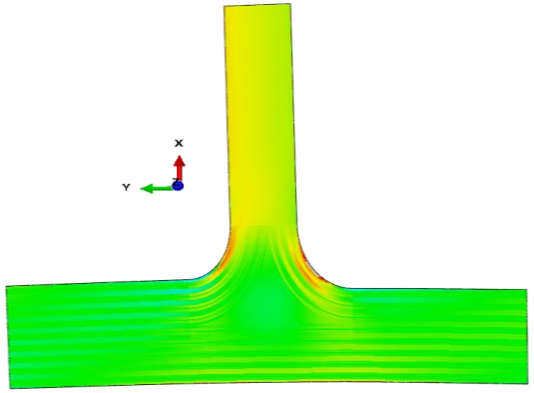
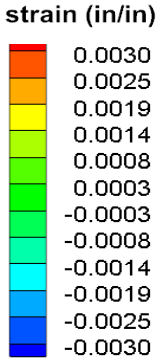


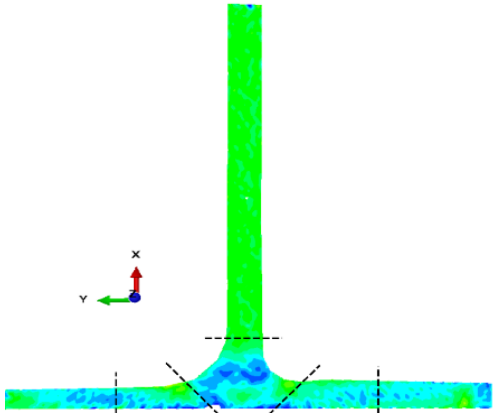
3-D Model

Global Y-Direction Tension



2-D Model





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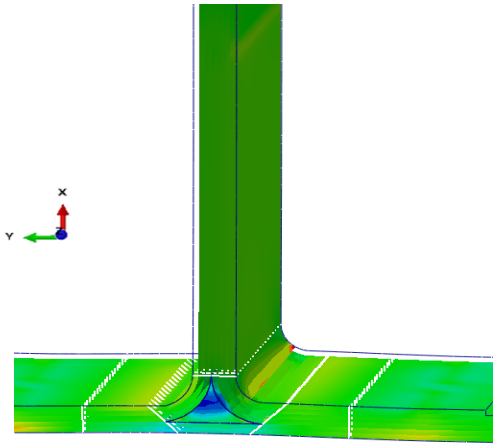
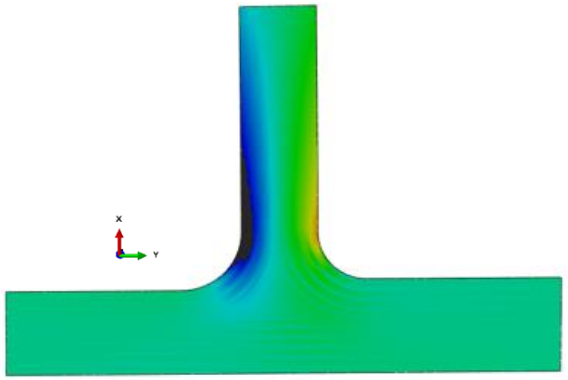


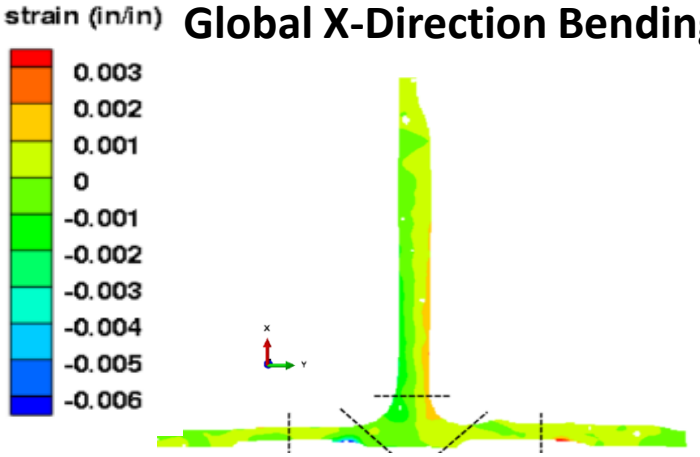
3-D Model

Finite Element Analysis and Results: Stitched Bending



2-D Model

Global X-Direction Bending



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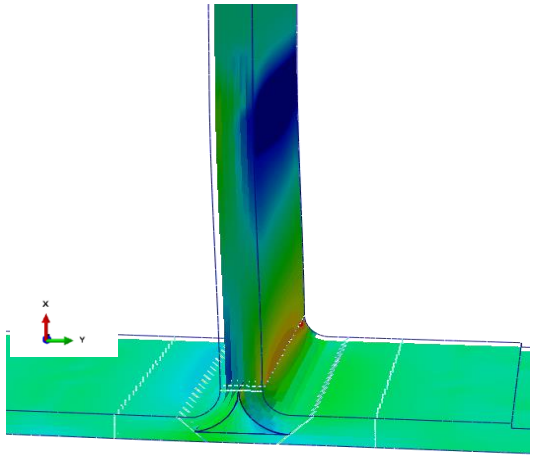
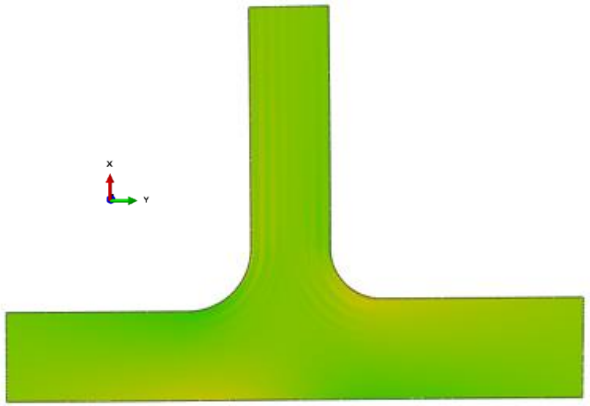
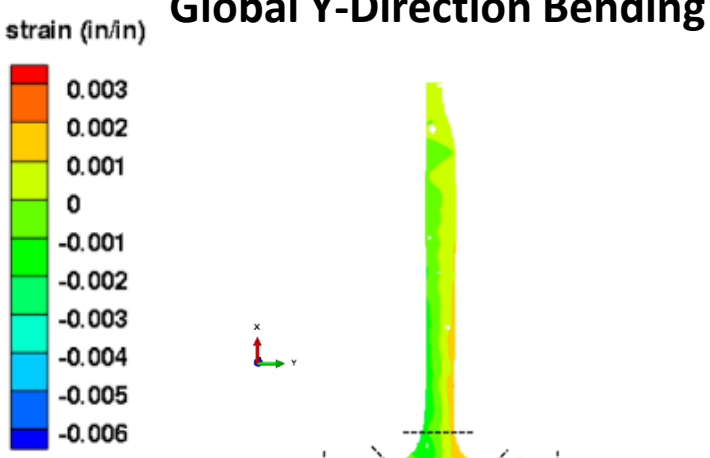


3-D Model

Global Y-Direction Bending



2-D Model



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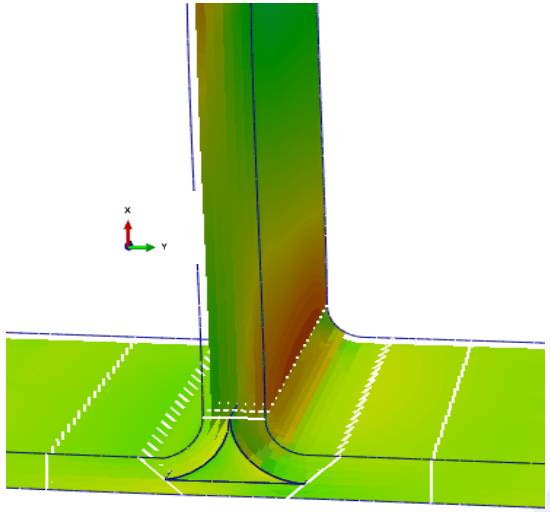

3-D Model

Concluding Remarks

- **Stitched and resin infused composite structures are being investigated within the HiCAM project as a possible technology to increase composite aircraft manufacturing rate**
- **2-D and 3-D models of previous tests conducted at LaRC were developed and investigated to establish analysis methods for use in HiCAM and other projects**
  - 2-D for preliminary sizing
  - 3-D for intermediate design analysis
- **Results were satisfactory; further refinement possible via cohesive elements between plies**
- **Future work will include DIC data for non-stitched and stitched T-cap specimens that are being fabricated and will be tested in HiCAM**

QUESTIONS?