Tool Shape Compensation for Composite Laminate Parts and CTE Characterization for Encapsulants

CMS Phase II Inner Tracker Service Cylinder

Composites Manufacturing & Simulation Center (CMSC) – Purdue University

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On behalf of CMS

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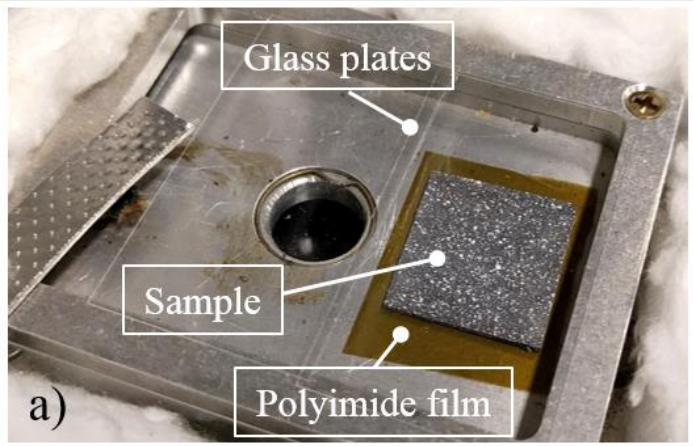
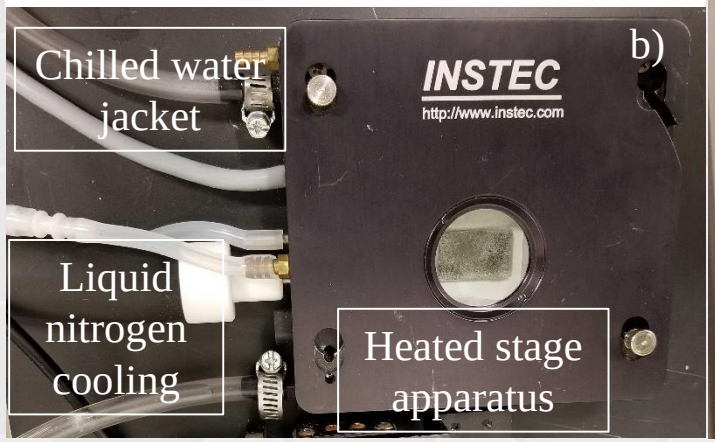
Forum on Tracking Detector Mechanics 2019 at Cornell University

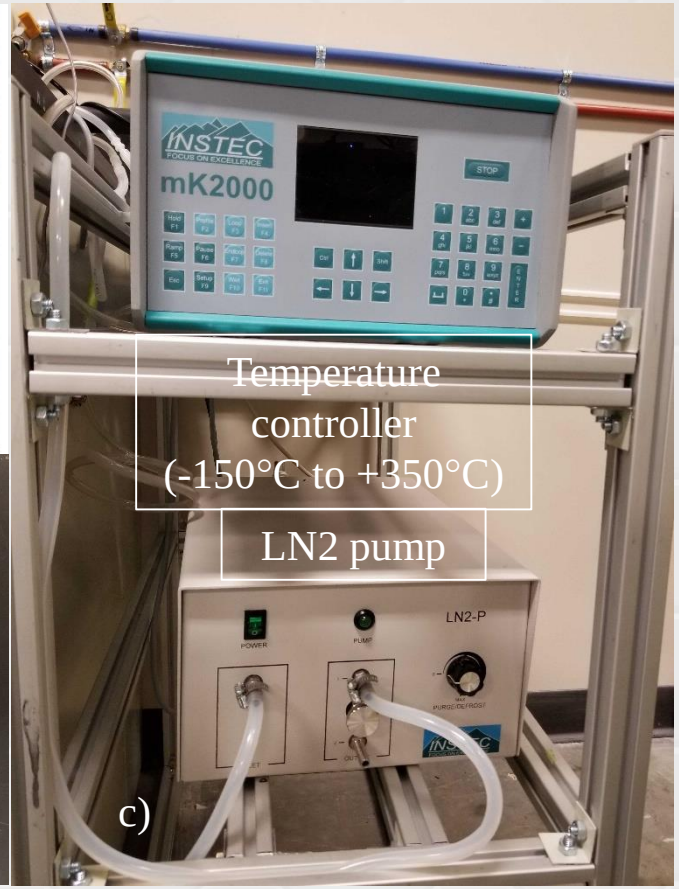
OUTLINE

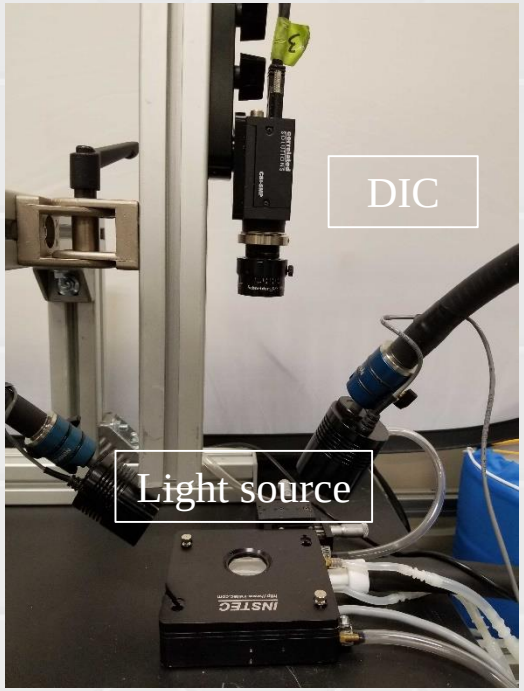
1. CTE Characterization for Encapsulants
2. Spring-in Simulation Work Flow
3. Tool Shape Compensation for Radial Stiffeners
4. Additive 3D Simulation Work Flow – Bonding Jig for Radial Stiffeners

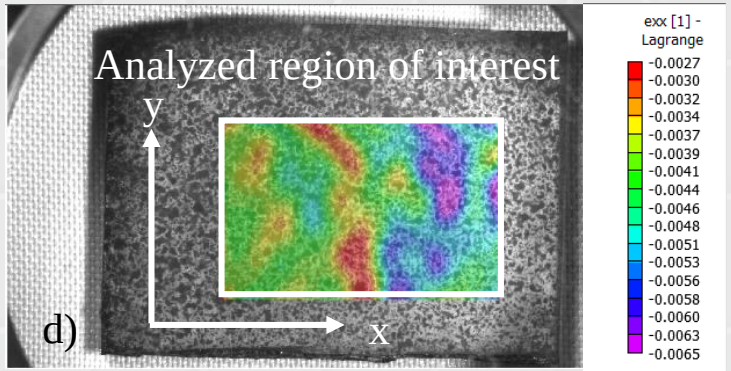
CTE Measurements – Experimental Setup



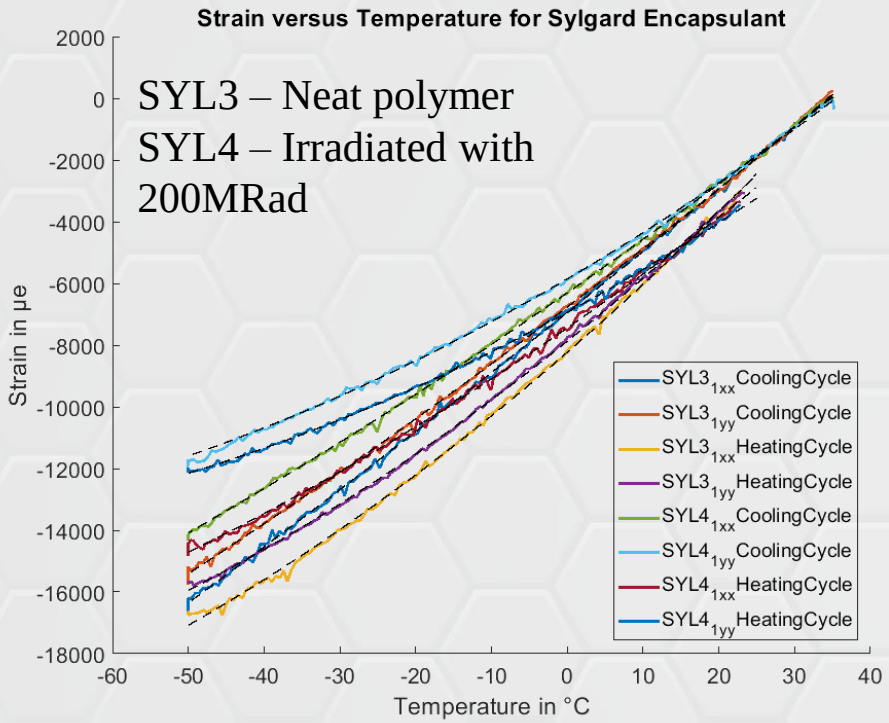


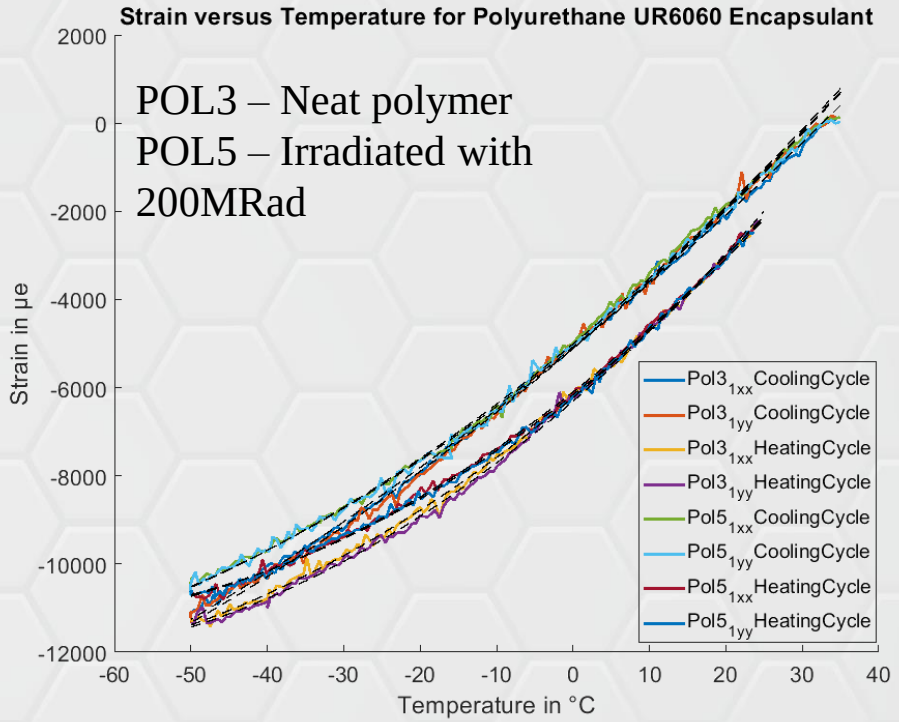






CTE Measurements – Results

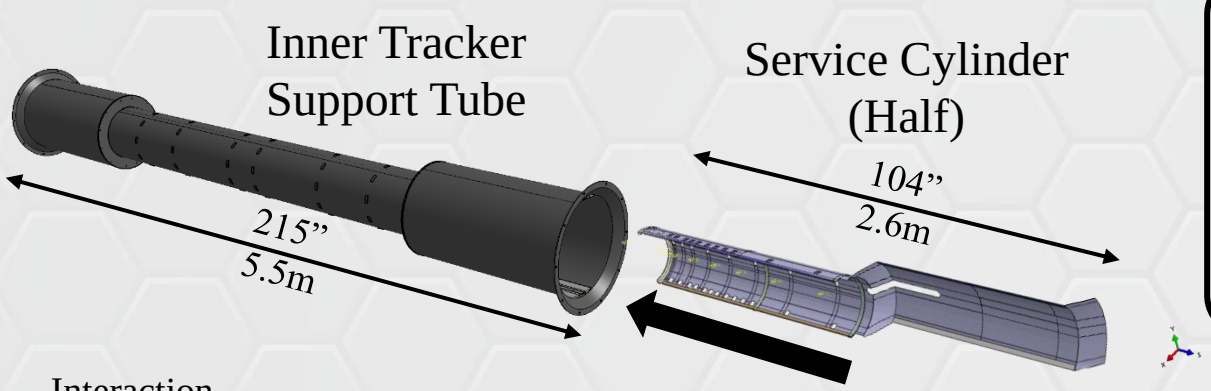




CMS – Work in Progress

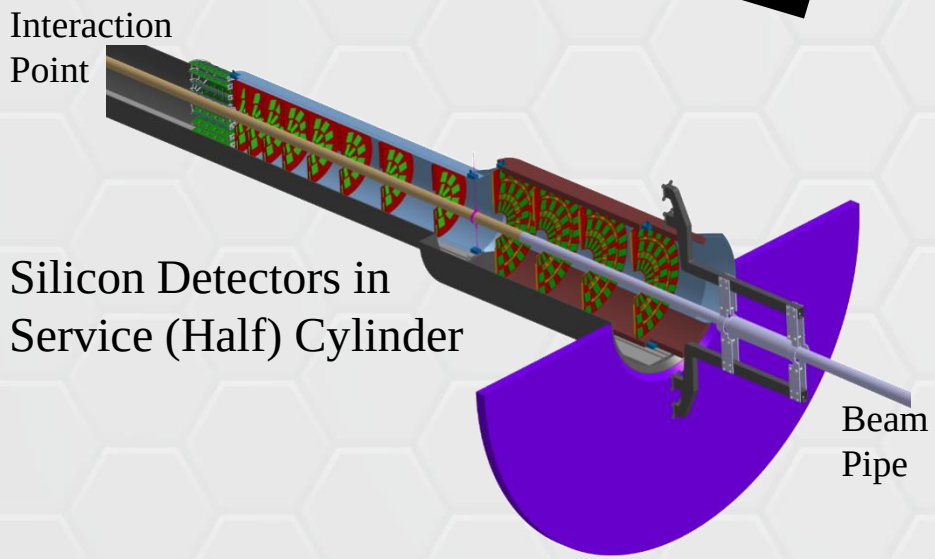
Sample	Description	CTE (με/°C)
SYL3	Sylgard – Neat polymer	$(0.5 \pm 0.2) * T + (198.4 \pm 9.6)$
SYL4	Sylgard – Radiated with 200 MRad dose	$(0.5 \pm 0.1) * T + (154.6 \pm 16.2)$
POL3	Polyurethane UR6060 – Neat polymer	$(0.7 \pm 0.2) * T + (146.4 \pm 2.7)$
POL5	Polyurethane UR6060 – Radiated with 200 MRad dose	$(0.7 \pm 0.1) * T + (139.3 \pm 2.8)$

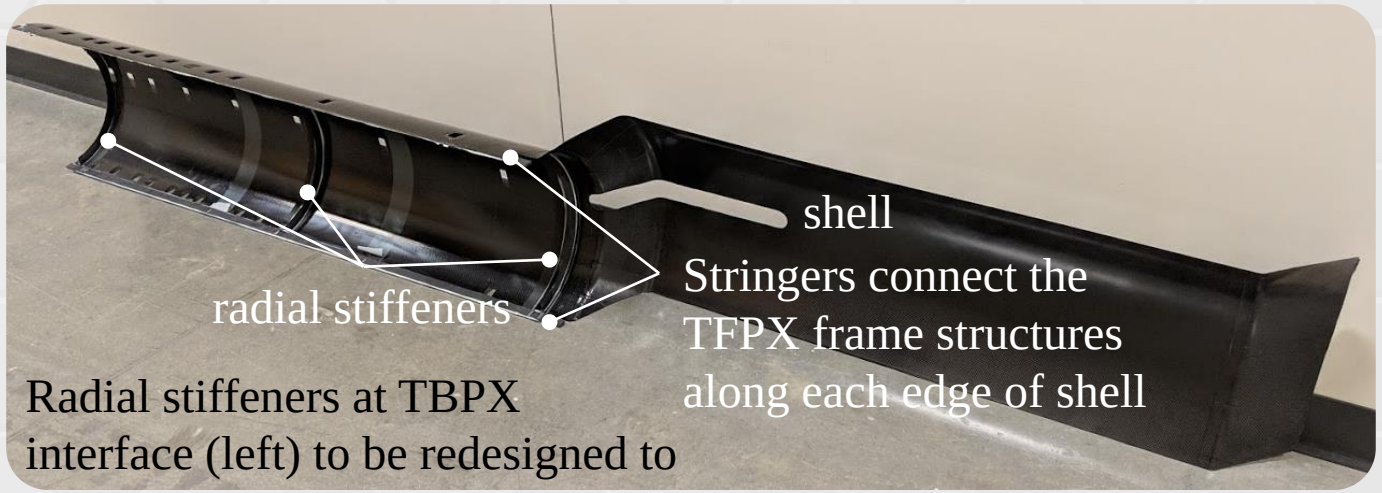
Inner Tracker Structure



- Designed 3 kg composite structure to support ~25 kg* detector and services
- Fabricated prototype service cylinder
- Validated structural simulations

*Specified at time of design. Closer to 40kg in latest.



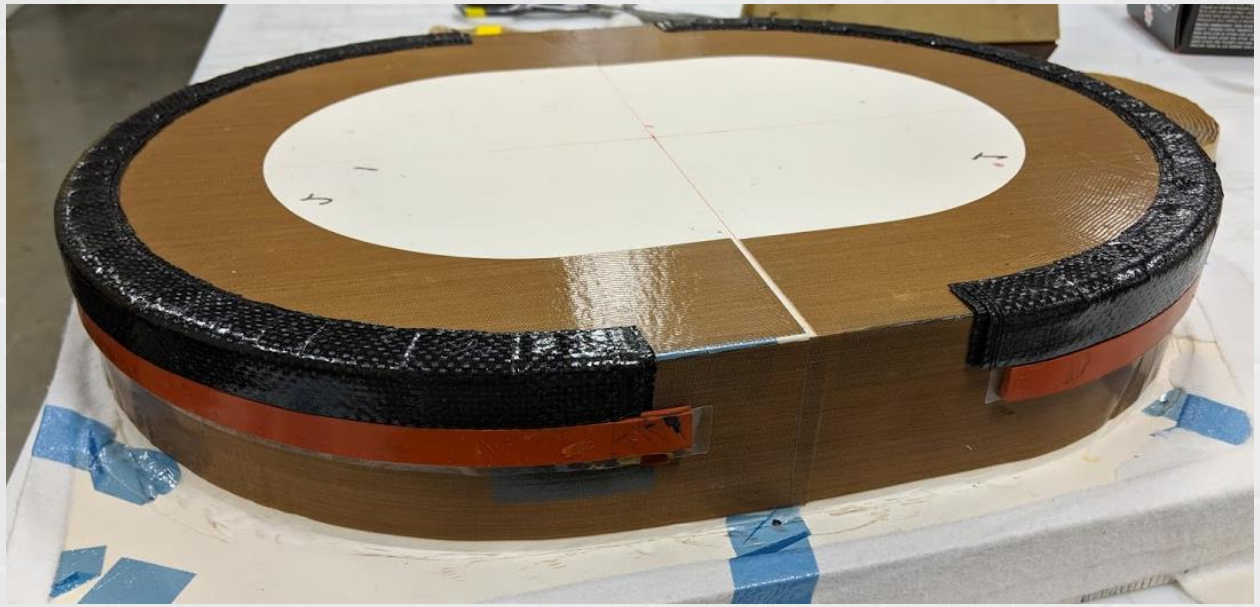


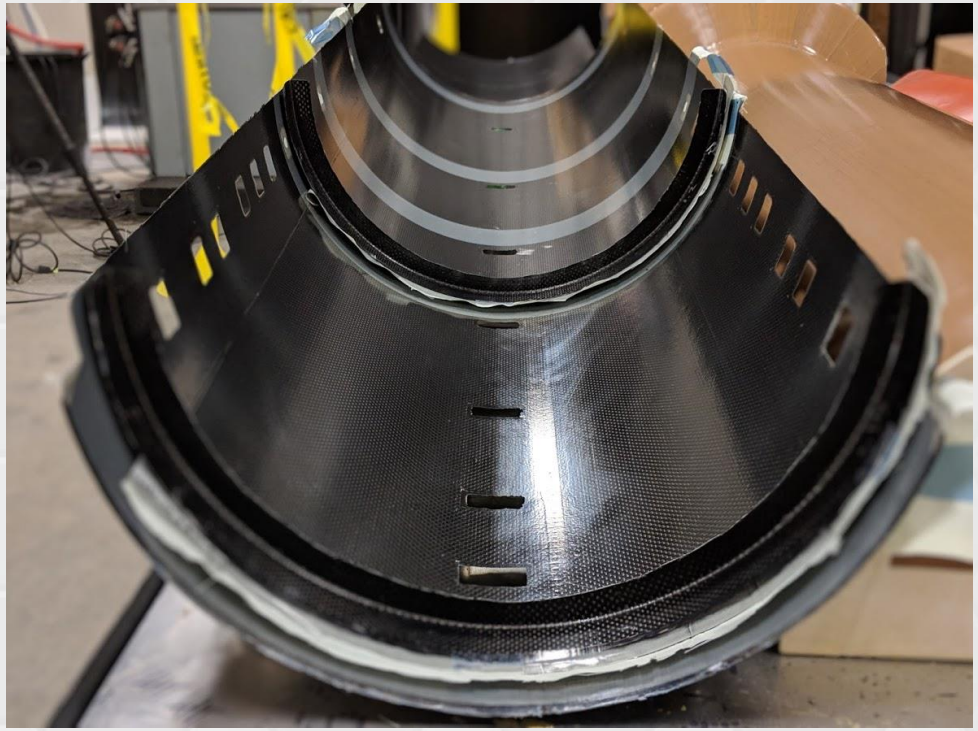
Radial stiffeners at TBPX interface (left) to be redesigned to act as TBPX mount point – will help with TFPX stiffness locally

Reinforcing Radial Stiffeners Fabrication

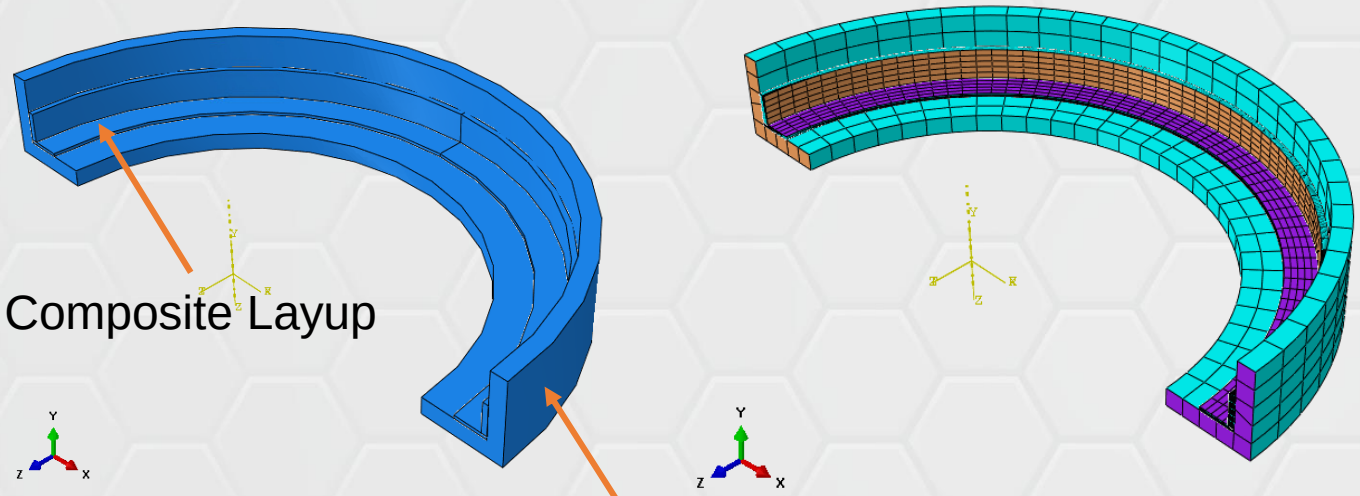
- Manufactured L-profile, C-shaped Radial Stiffeners as structural reinforcements
- Frames adhered to shell via post-cure bonding operation
- Need to choose rad-hard adhesive for future

- Radial Stiffeners determine the shape of the service cylinder





SPRING-IN SIMULATION WORK FLOW



1. MODEL SET-UP

part geometry, nominal tool geometry & ply cut out, assign local material orientation, initial/boundary conditions

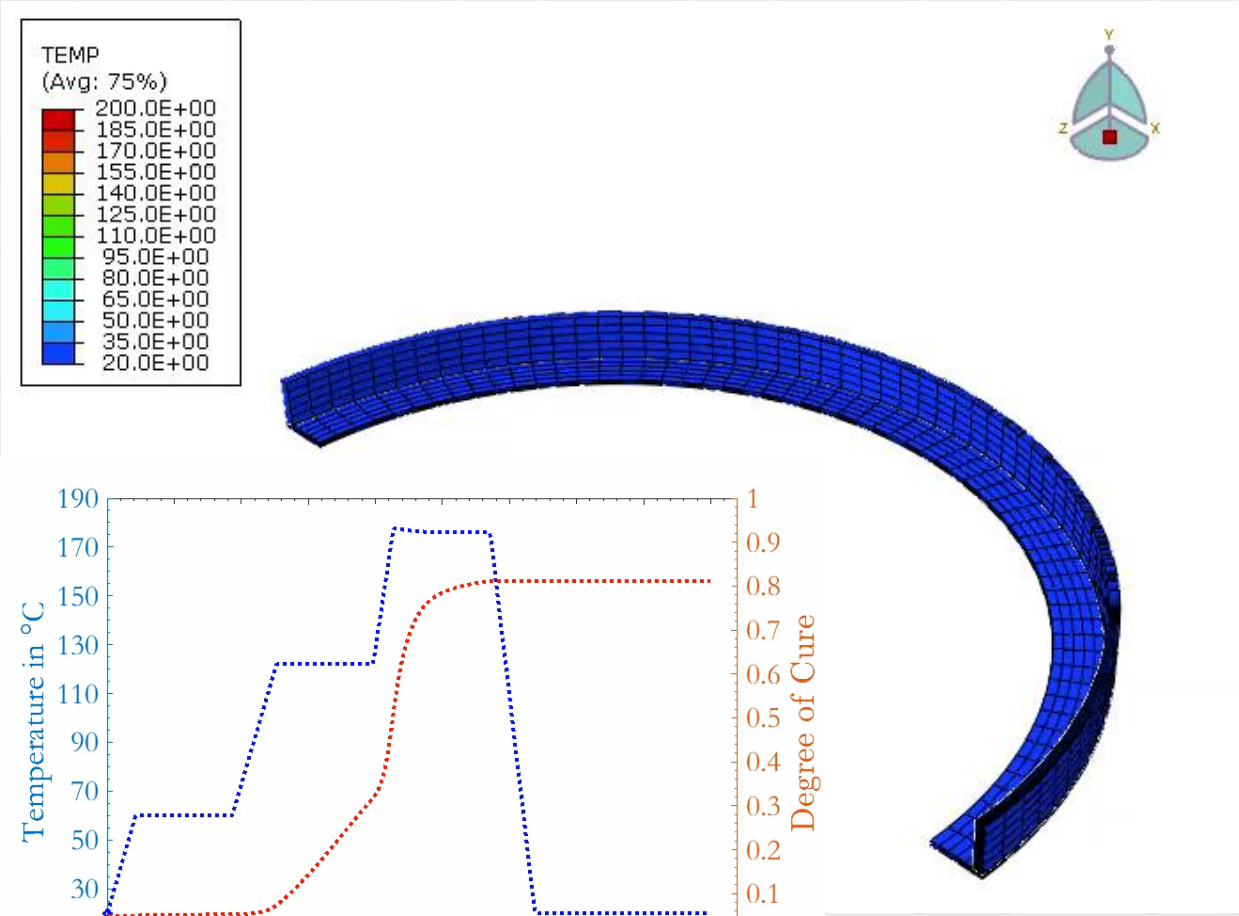
Geometry (CATIA)

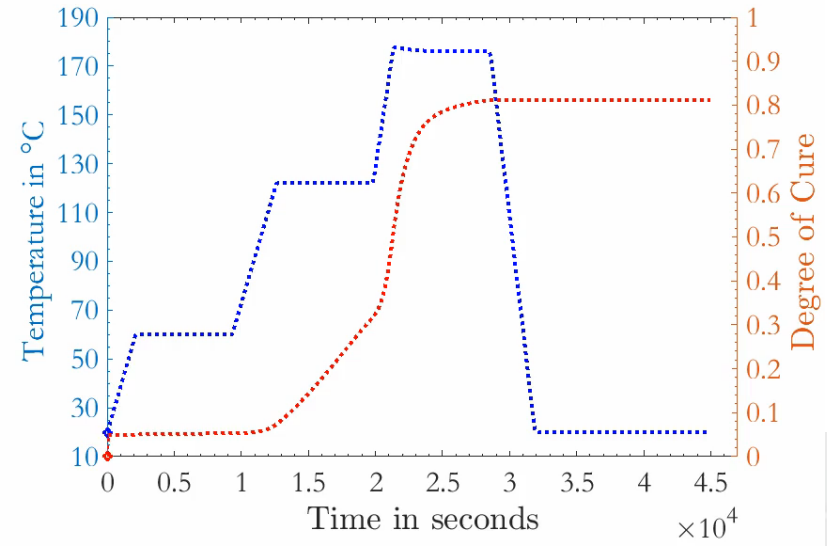
↓

Set up FE Model (SIMULIA)

SPRING-IN SIMULATION WORK FLOW

Unit : °C





2. THERMO-CHEMICAL ANALYSIS

cure kinetics, heat transfer between ambient & the tool-part assembly, heat generation -chemical cure reaction

Define Cure Conditions

Thermal History & Degree of Cure

SPRING-IN SIMULATION WORK FLOW

CONVERGENT MANUFACTURING TECHNOLOGIES

3. FLOW-COMPACTION ANALYSIS

resin (Darcy) flow relative to elastic porous fiber-bed, pressure load development in resin, change in laminate thickness

SIMULIA

Fiber Volume Fraction Computation

CONVERGENT MANUFACTURING TECHNOLOGIES

4. STRESS-DEFORMATION ANALYSIS

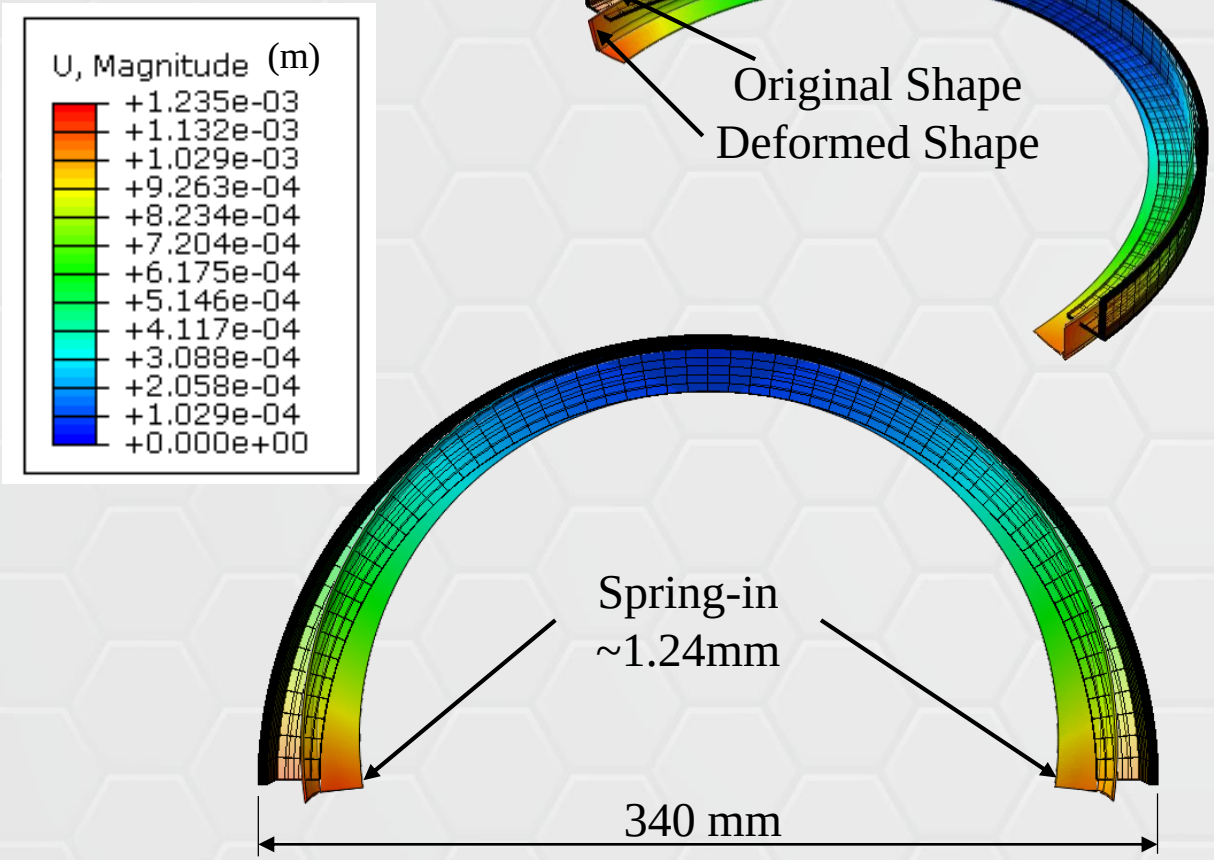
process induced deformations & residual stress, mismatch of thermal-mechanical properties, cure shrinkage & tool part interaction

SIMULIA

Deformed Shape & Residual Stress State

Material properties are updated at each solution step to account for the progression of cure and the subsequent change in thermal properties.

TOOL SHAPE COMPENSATION FOR RADIAL STIFFENERS



Visual deformation scaling 20x

5. COMPENSATED TOOL SHAPE GENERATION

deformed shape inverted about nominal

SOLIDWORKS SIMULIA

Tool Shape used for Thermal Deformation Analysis of the Tooling Material

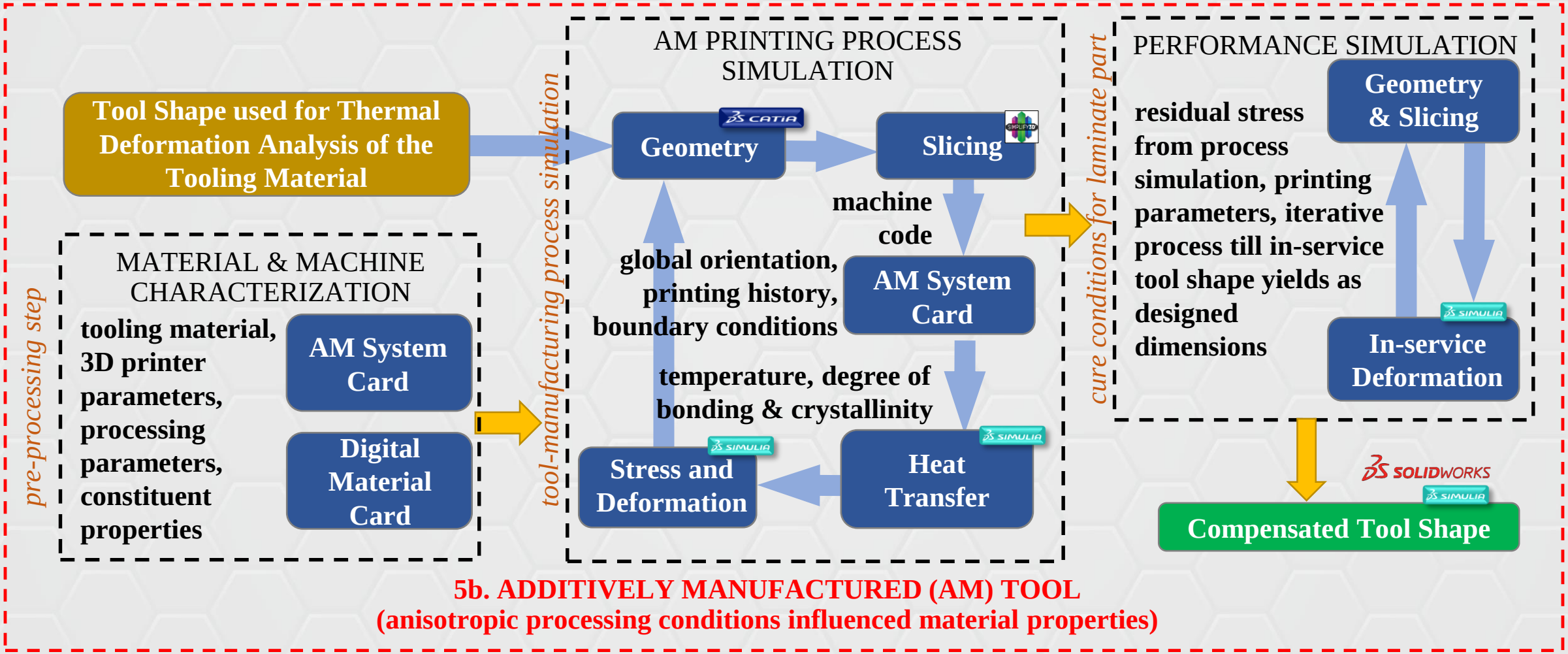
material properties (tool)

SOLIDWORKS SIMULIA

Compensated Tool Shape

5a. TOOLING BOARD TOOL (isotropic material properties)

ADDITIVE 3D SIMULATION WORK FLOW



Model Setup → Thermo-Chemical → Flow Compaction → Stress Deformation → Tool Shape Compensation

CAMRI – Process Monitoring

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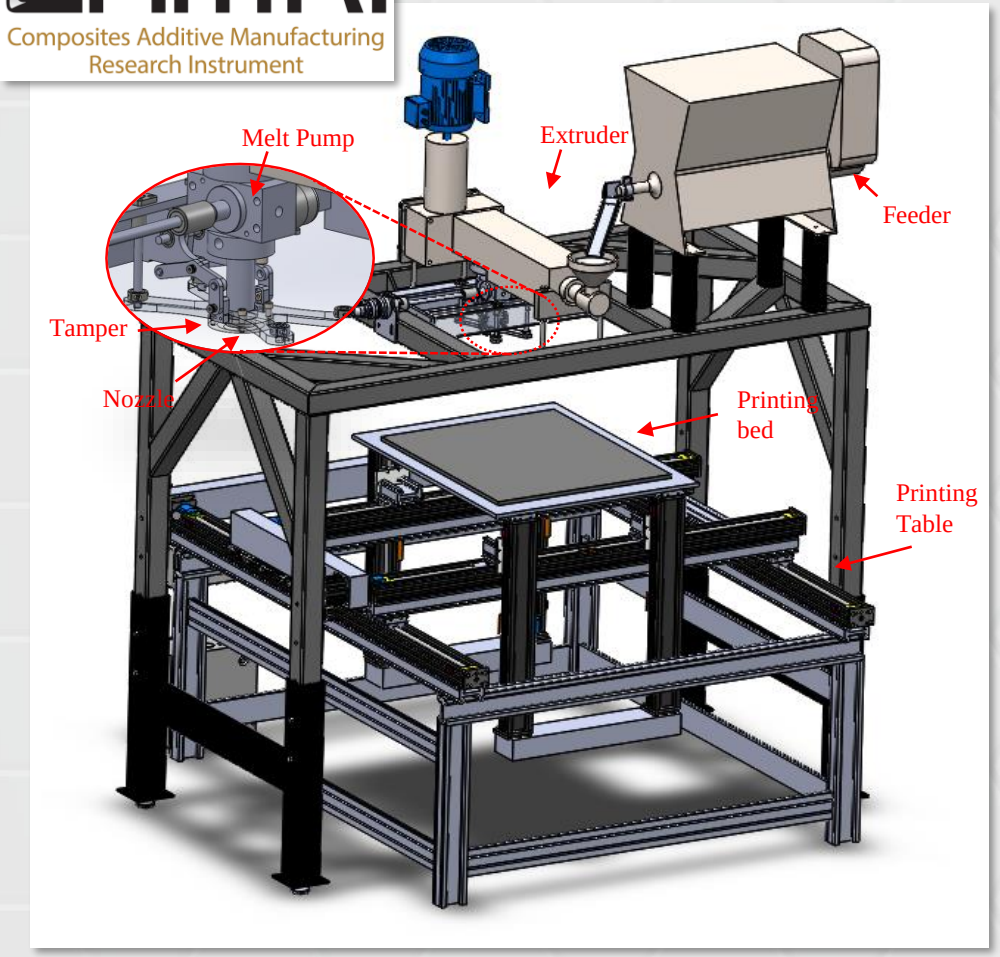
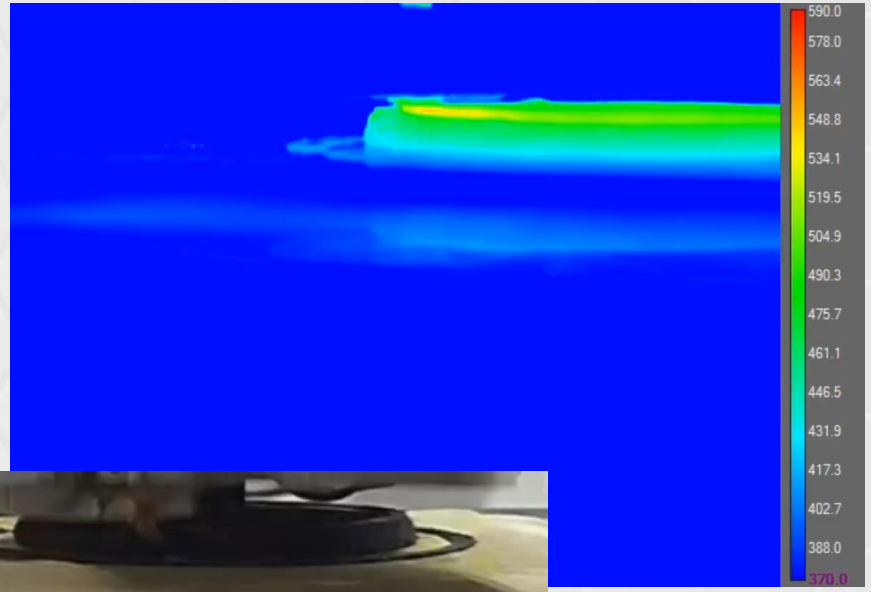
Purdue University

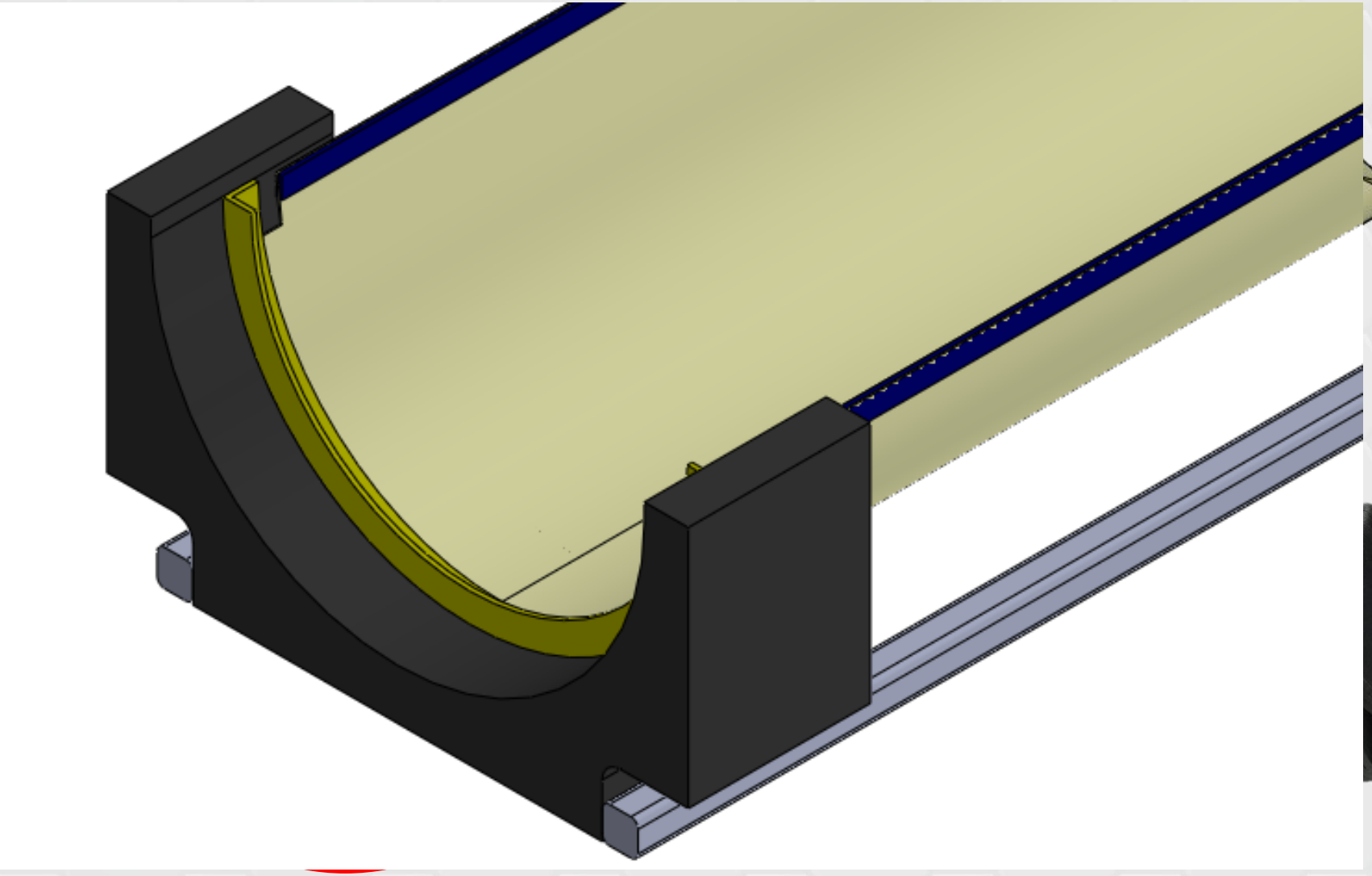
CAMRI
Composites Additive Manufacturing Research Instrument

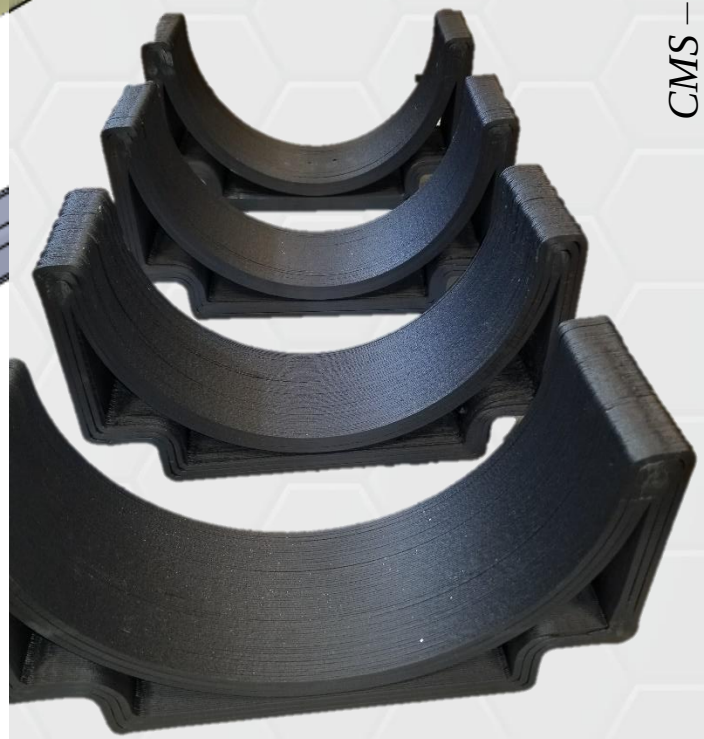




Video 10X

Bonding Jig for Radial Stiffeners





CMS – Work in Progress

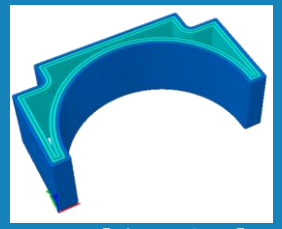
AM Printing Process Simulation

Composites Manufacturing & Simulation Center ™

PURDUE UNIVERSITY

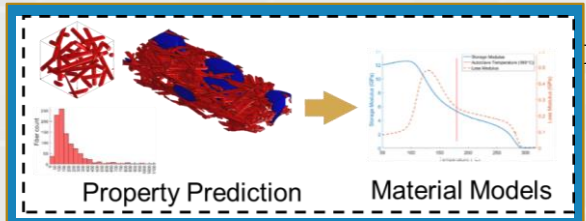
CMS – Work in Progress

Inputs



Machine Code

AM System Card



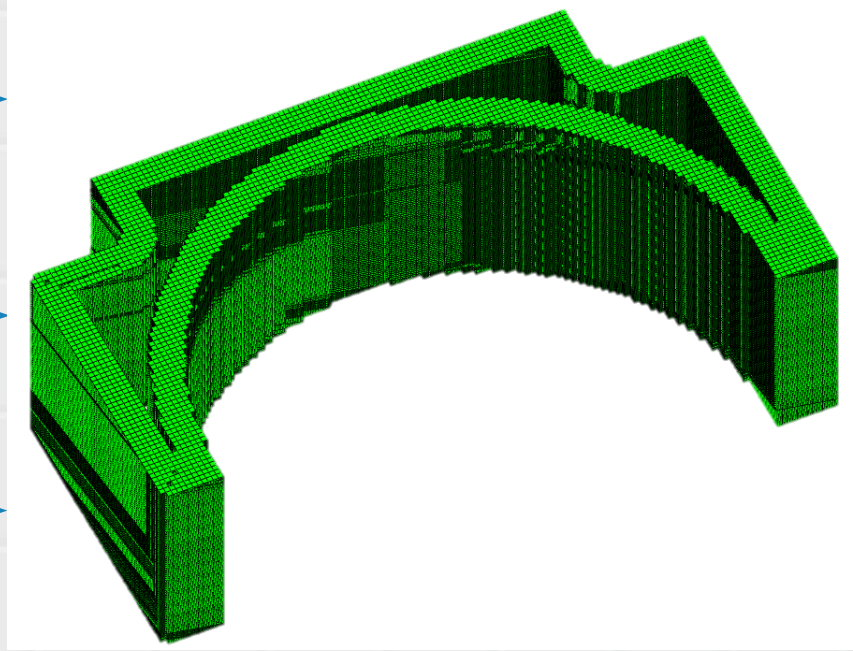
Digital Material Card

Global Fiber Orientation

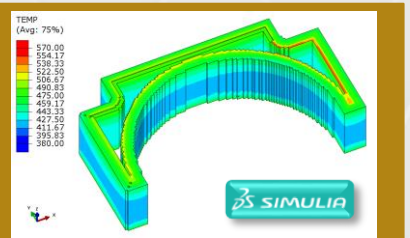
Boundary Conditions

Material Models

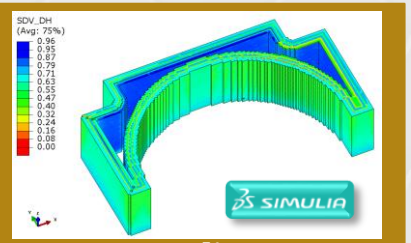
FEA Process Simulation



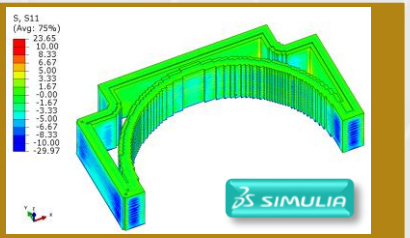
Outputs



Temperature



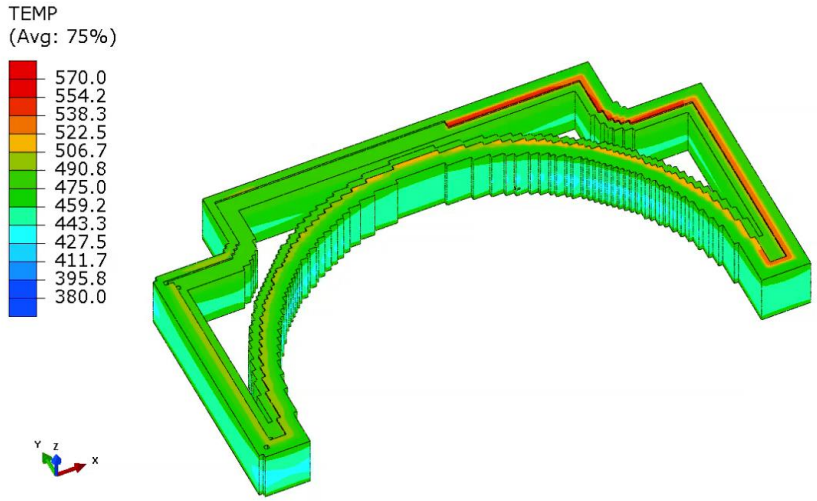
Bonding



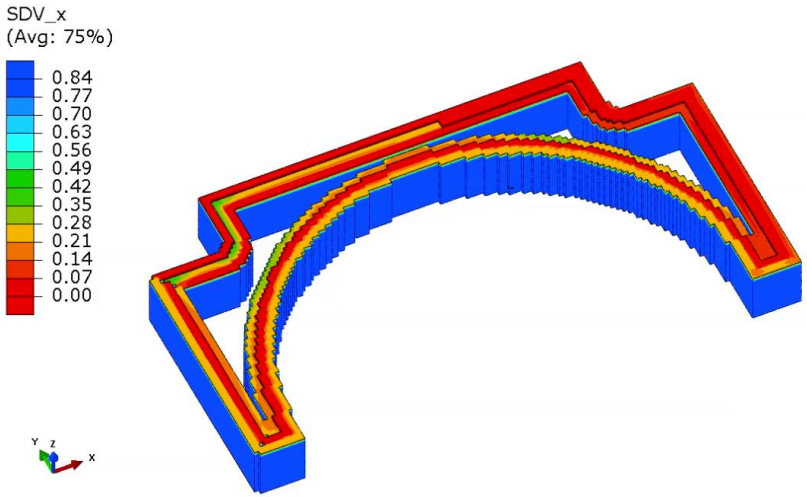
Residual Stress

AM PRINTING PROCESS SIMULATION RESULTS

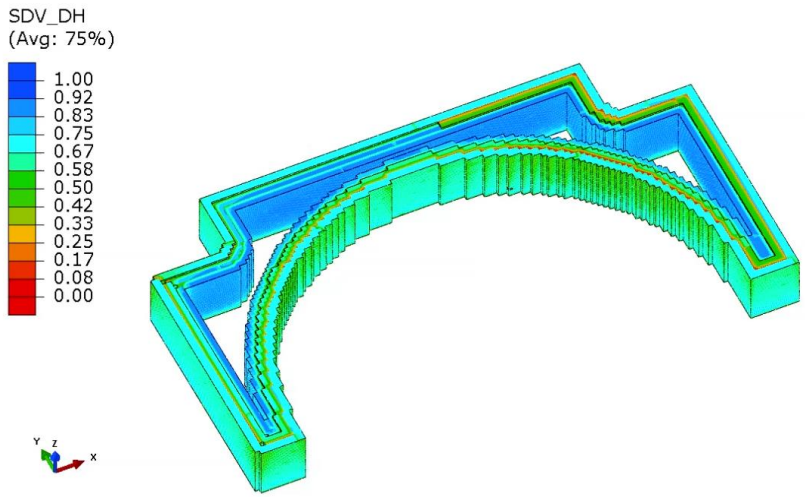
Temperature (K)



Crystallinity



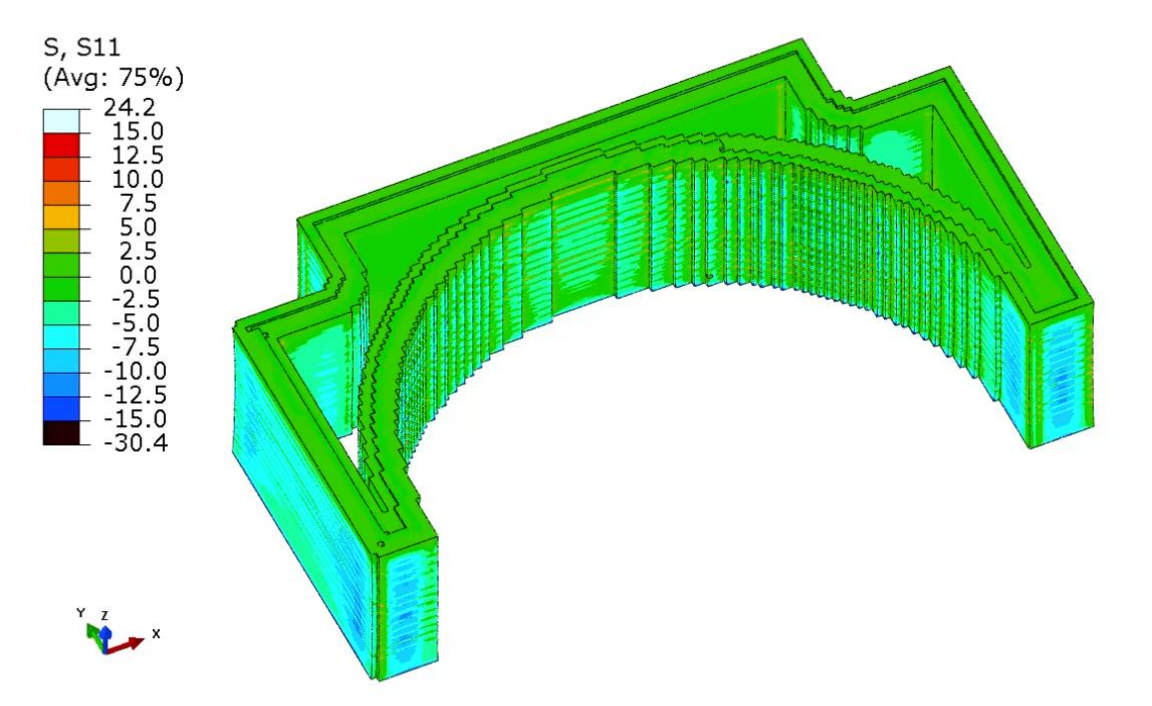
Interlayer Bonding



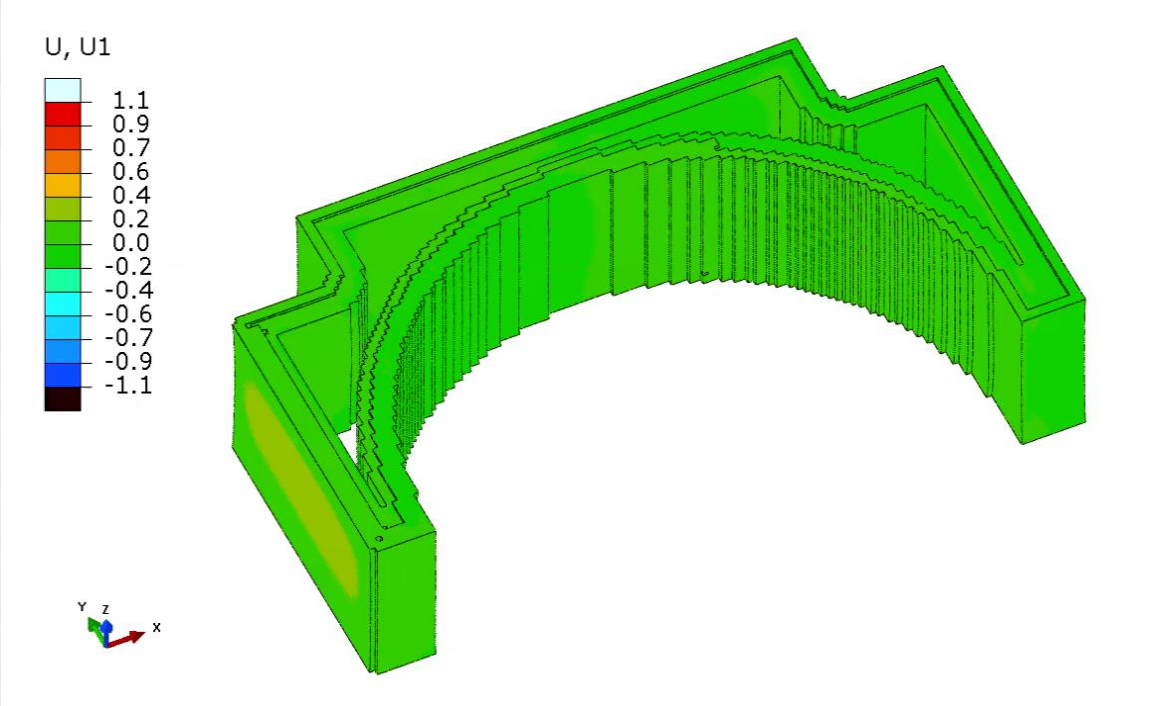
80x Printing Speed

AM PRINTING PROCESS SIMULATION RESULTS

Stress - σ_{11} (MPa)



Deformation - $U_x \ - (mm)$

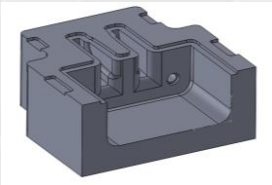


10x Deformation & 80x Printing Speed

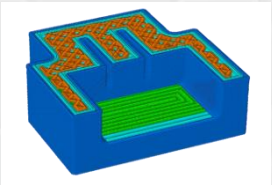
An Integrated Workflow for AM Design

Modify Geometry

Geometry

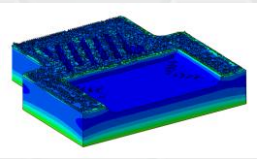


CAD

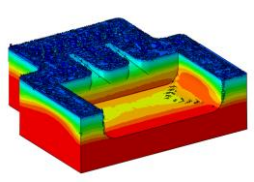


Sliced CAD

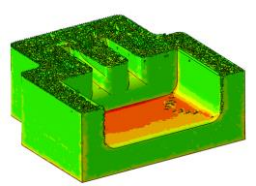
EDAM Process Simulation



Temperature

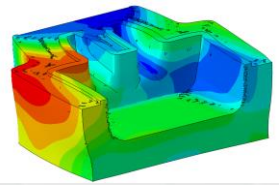


Polymer Crystallization

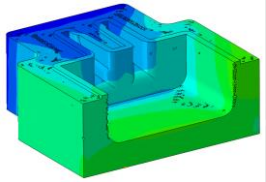


Residual Stress

Performance Simulation

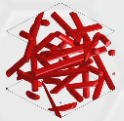


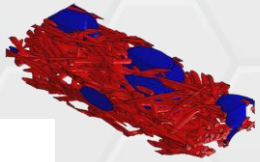
Creep

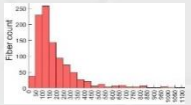


Shape Change

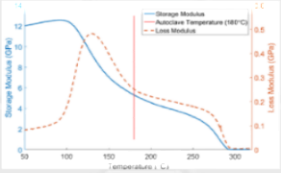
Digital Material Card







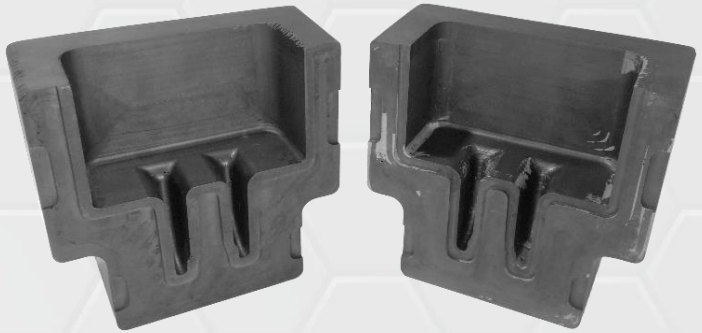
Property Prediction



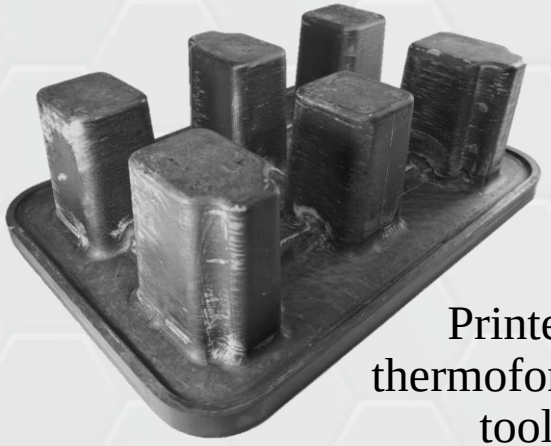
Material Models

Composite Tools Fabricated With CAMRI

Autoclave tools



Printed compression molding tools



Printed thermoforming tool

VARTM tool

Printed stamping tools

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- Dr. Andreas Jung and Purdue PSDL team for collaboration and bringing CMSC into project
- Yadira Bordlemay Padilla, Mechanical Engineer, Cornell University
- Dr. John Conway, UC Davis for consulting about design
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- Bobby Stines at Statt Engineering for tooling board machining