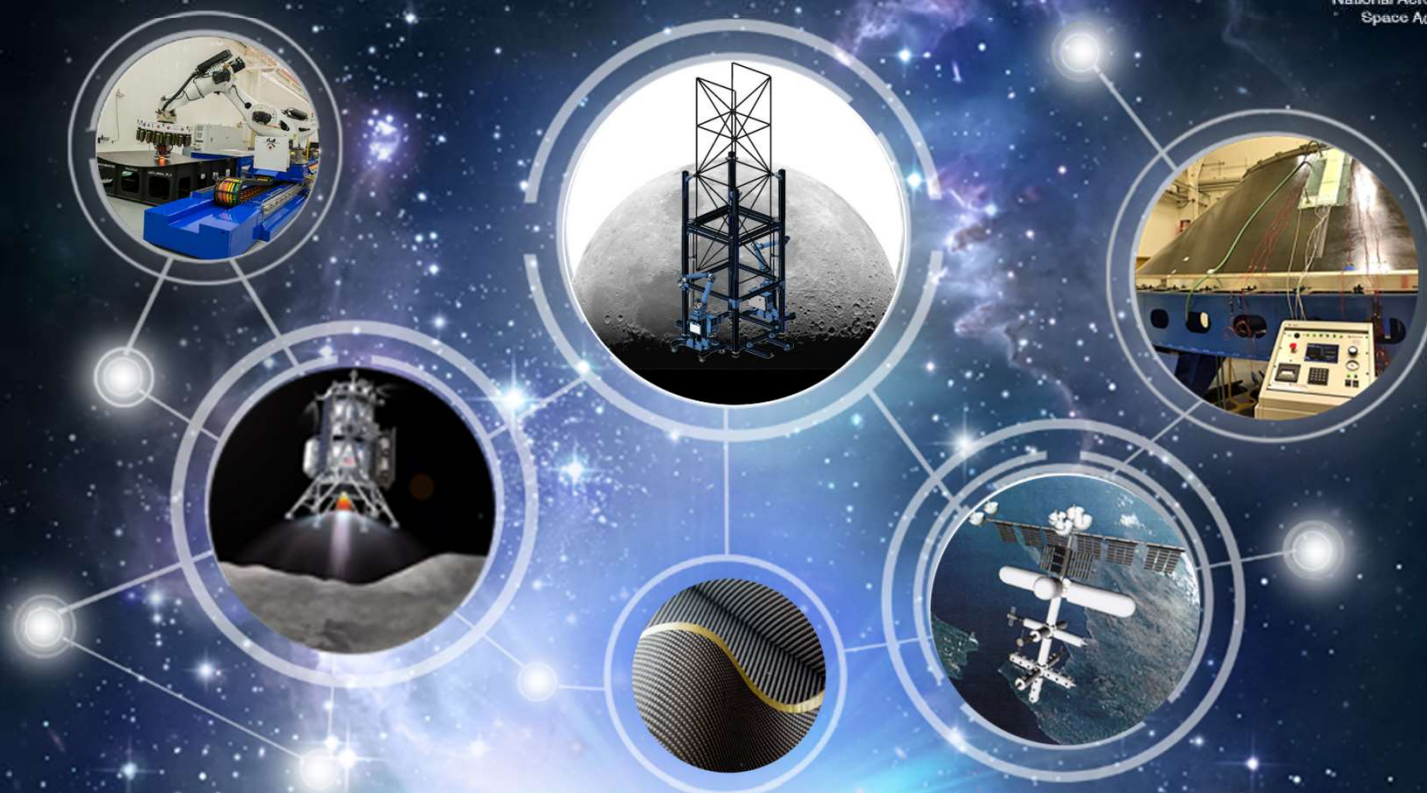




Space Technology Mission Directorate Game Changing Development Program

Drew Bergan, Thermoplastics Development for Exploration Applications (TDEA) | Annual Program Review | September 10-12, 2024

TDEA Overview



Timer

Needs Addressed by Project

OSAM, HLS, SMD, SLS	Adhesive Bonding Thermosets and Welding Thermoplastics
OSAM, HLS, SMD, SLS	Thermoplastic Composites for Space Applications

Project Goals

Goal #1	To advance NASA's thermoplastic composites capabilities by developing structurally efficient joining solutions for large-scale space structures and applications to support NASA's future exploration missions.
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Project Objectives

Objective #1	Assess the current capability for design, analysis, and manufacture of commercially available thermoplastic material systems for large-scale space structures and on-orbit applications.
Objective #2	Evaluate thermoplastic composite material systems for large-scale space structures and on-orbit applications .
Objective #3	Develop NASA's in-house capabilities for thermoplastic composites processing and manufacturing.
Objective #4	Develop and understand advanced thermoplastic joining technique(s) relevant to space environments and applicable to unitized and/or reconfigurable composite structures.
Objective #5	Advance structural analysis capabilities for the design and analysis including failure prediction of thermoplastic composites including joints.

Orange – reduced scope due to closeout in FY24

TDEA Team Operations & Partnerships



NASA Centers

- Glenn Research Center: Materials, Analysis, NDE
- Goddard Space Flight Center: Design, Analysis, NDE
- Langley Research Center: Analysis, Materials, NDE
- Marshall Space Flight Center: Manufacturing, Mgmt.

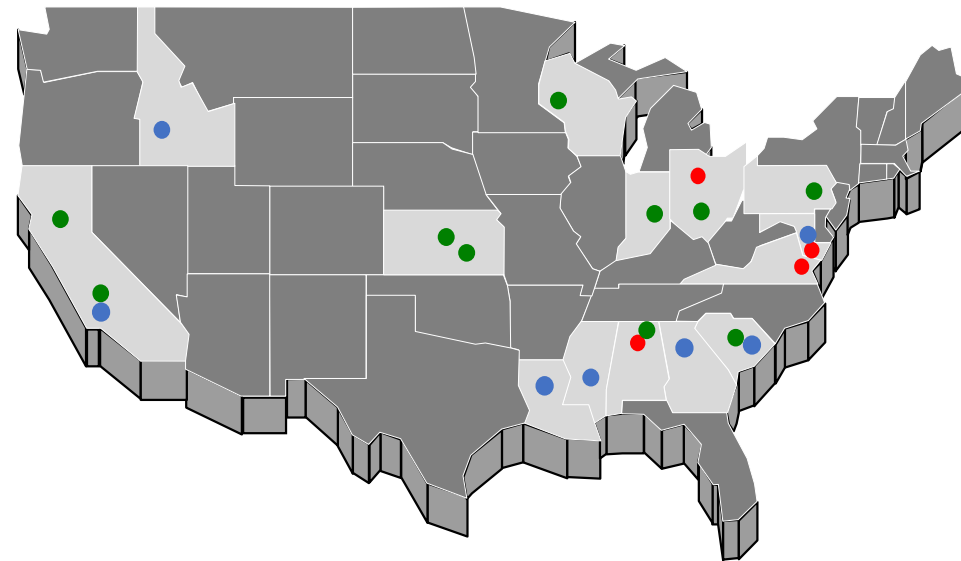
- *NASA composites team started in 2004*
- *Core team together since CTE project started in 2015*
- *With no composites funding in FY25 team is getting broken up*

Partners

- | | |
|---|---------------------------------|
| • Agile Ultrasonics | • Mantis Composites |
| • Boise State University | • NIAR/Wichita State University |
| • Hexagon/MSC Digimat | • SABIC |
| • Kratos Defense (formerly Southern Research Eng. Division) | • Solvay |
| • Teijin | • Spirit Aerosystems |
| • Toray | |
| • Victrex | |

Collaborators, Technical exchange

- Lockheed Martin Corporation (SMART-C ACO)
- Northrop Grumman Corporation
- The Boeing Company
- Boise State University
- University of Southern Mississippi
- Georgia Institute of Technology
- University of Southern Carolina, McNair Center

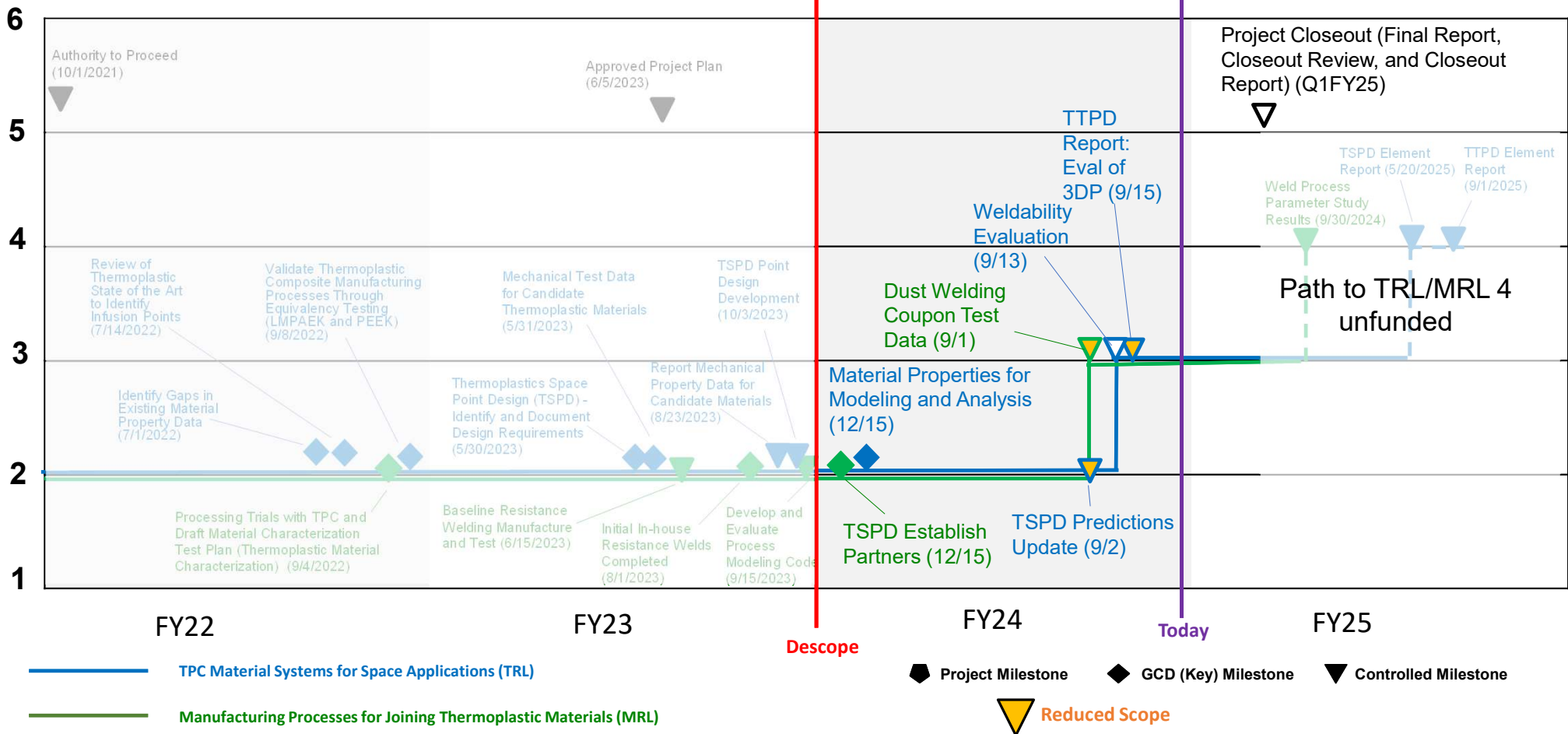


TDEA TRL/MRL/MoRL Chart



Timer

TRL / MRL



TDEA Assessment Summary



Timer

Project Name	Performance				Comments
	C	S	T	P	
Annual					Technical – Green Cost – Green Schedule – Green Programmatic – Green

	Oct	Nov	Dec	Jan	Feb	MYR	Apr	May	Jun	Jul	Aug	APR
C												
S												
T												
P												

Project was notified (9/29/2023) by STMD and the GCD Program Office that there was a cut in project FY24 funding. The project was directed to closeout in FY24. Red because of replan for closeout.

Late April/ May: Re-scope plan completed and sent to the GCD program office for review and approval. Project received approval for new budget splits and center splits. Funding drops were made. Project has now received 100% of re-scope allocation.

TDEA Accomplishments

Technical Progress: Roadmap



Timer

1 State-of-the-art survey

2 Launch vehicle structure mass savings

How much mass savings with a postbuckled skin design?

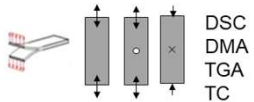


Promising concepts for TPC launch vehicle structures can be carried forward in future work

3 TPC material characterization

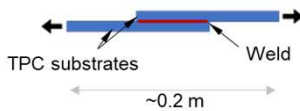
Material properties for material selection and model inputs

Thermal, mechanical, and physical tests



- Emphasis on data required for process, material, and structural model inputs

4 Welded joint pathfinder: Foundational developments

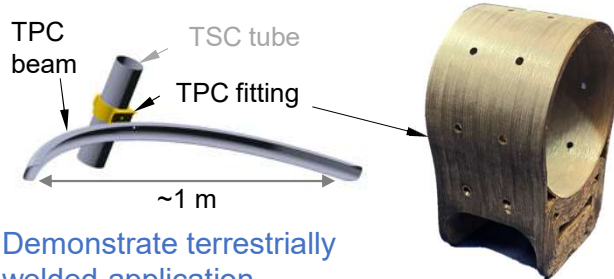
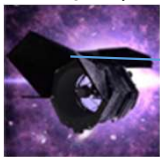


- Experiments to characterize weld performance, efficiency, and robustness across several materials and weld methods

5 Thermoplastic Terrestrial Point Design (TTPD):

TDEA terrestrial based welding design concept :
Confidence building application

Roman space telescope (RST)



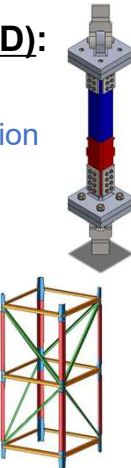
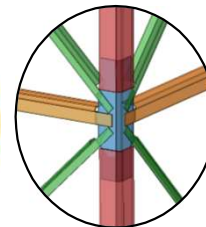
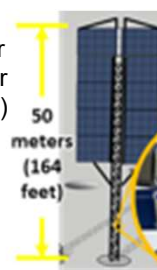
- Demonstrate terrestrially welded application

6 Thermoplastic in-Space Point Design (TSPD):

Game Changing application

- Developments for in-space welding application
- Demonstrate scale-up and dust tolerance

Tall lunar tower (TLT)



TDEA Accomplishments Expanded Material Property Database

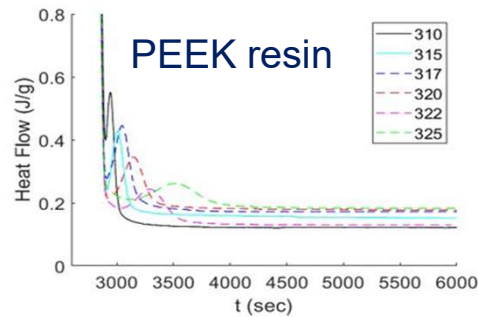
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Timer

DSC- Differential Scanning Calorimetry

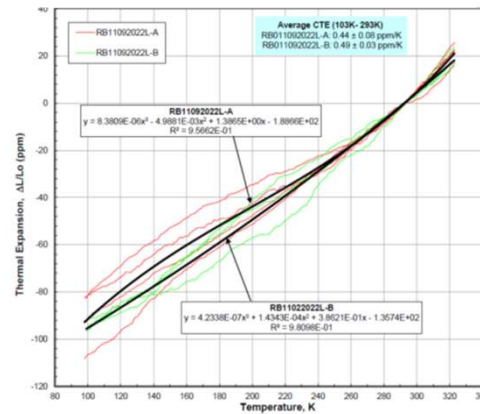
- Evaluate the crystallization kinetics of candidate materials as relevant to crystallization on welding.



Coordinated test requirements and reviewed data with analysis team.

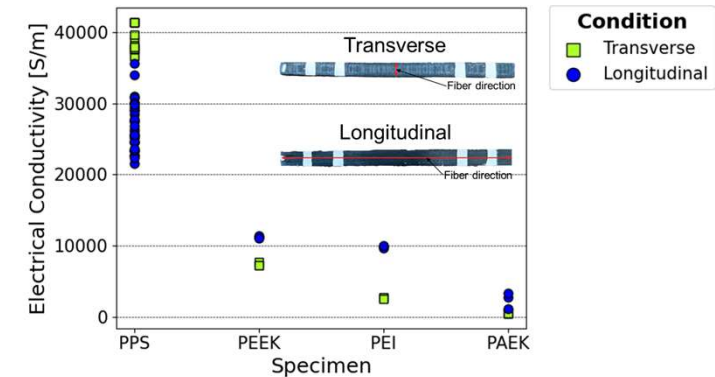
CTE- Coefficient of Thermal Expansion

- Measured from -170°C
- Thermostructural analysis



Electrical Conductivity:

- Measured as a function of material crystallinity
- Process modeling



Additional characterization:

Dynamic mechanical analysis: complex modulus

Thermal Conductivity: process modeling and thermal analysis

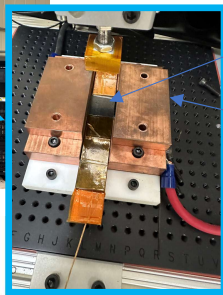
Out-gassing: in-space applicability

Thermogravimetric analysis: thermal stability

New material characterization data available for four commercially available thermoplastic composite material systems: over 250 tests completed

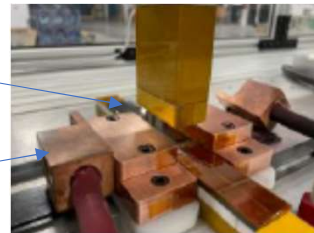
Materials	Resistance (RW)	Induction (IW)	Ultrasound (UW)
AS4/PEEK, TC1200	NIAR FY23, MSFC FY24	Spirit FY24	Agile FY24
AS4/PEI, Solvay APC, *Toray	NIAR FY23, NIAR FY24*	Spirit FY24	Agile FY24
T700/LM-PAEK, TC1225	NIAR FY24 (+3 heating elements)	Spirit FY24	Agile FY24 (pursued scale-up)
AS4/PPS, TC1100	NIAR FY24	Spirit FY24	Agile FY24
M30S/PEKK (Thin ply)	NIAR FY24	-	Agile FY24

MSFC RW setup

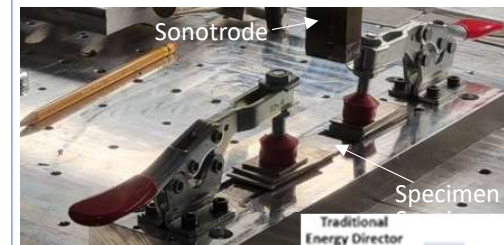
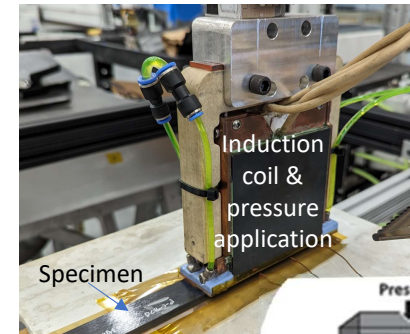


Specimen
Electrical connection

NIAR RW setup



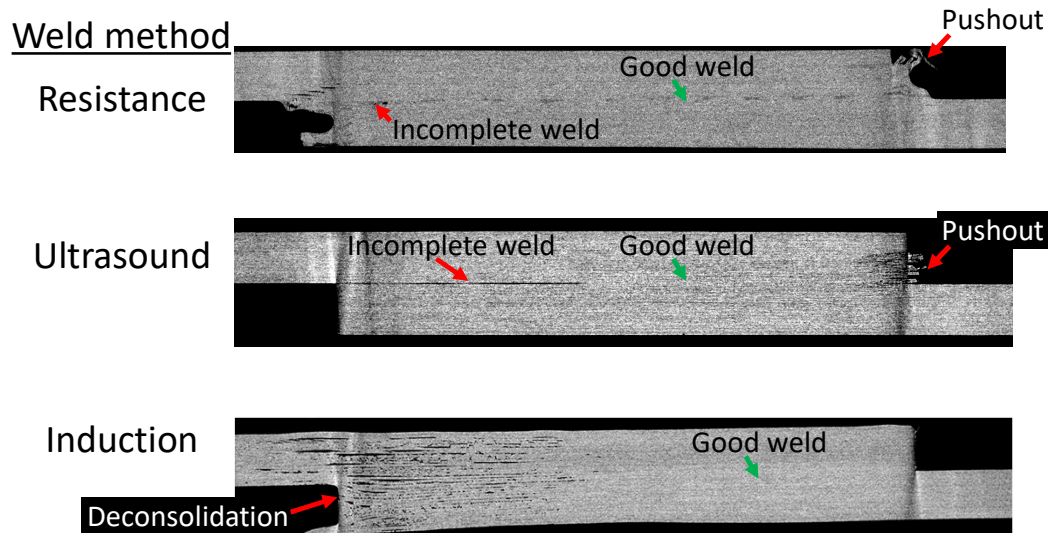
Using carbon-fiber
plain weave heating
element



Completed over 600 coupon (~1 in²) lap welds; gained new insights into advantages, challenges, and trade-offs in thermoplastic composite welding at small scale

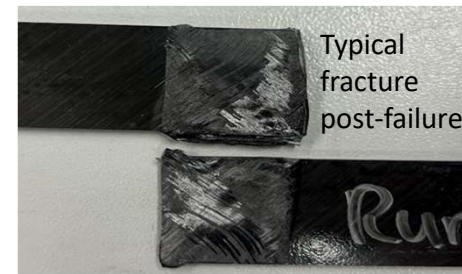
Welded joint performance assessed through nondestructive and destructive tests (KPP-2 for strength repeatability)

Non Destructive Evaluation (NDE): defects can occur in each welding method



X-Ray CT and ultrasonic NDE identify relevant defects; comparing results to microscopy

Mechanical test to characterize joint strength and repeatability (TC1225, UW)



Iteration	Mean strength (psi)	CoV (n=6)
1: Baseline	1420	23%
2: Updated tool, pre-heating	2250	9.8%

KPP-2 Coefficient of variation (CoV) threshold: 10%

Mechanical tests for each material/weld method:

- *Correlate process to NDE to strength*
- *Inform process updates to improve performance*

TDEA Accomplishments Models for Welding Processes

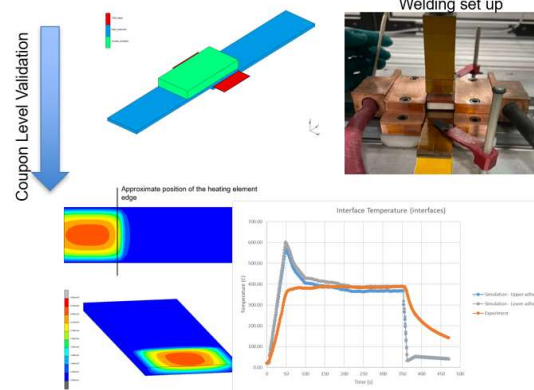
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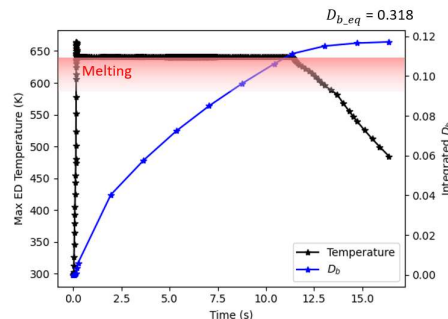
Model for Resistance Welding Process

Key Accomplishment:
Validated process models (thermo-electric and thermo-elastic) behavior for single lap and double lap welded coupon. Using Digimat & Marc software.



Model for Ultrasonic Welding Process

Key Accomplishment:
Developed a transient thermal model of the ultrasonic welding process using COMSOL. Added prediction of degree of bonding.



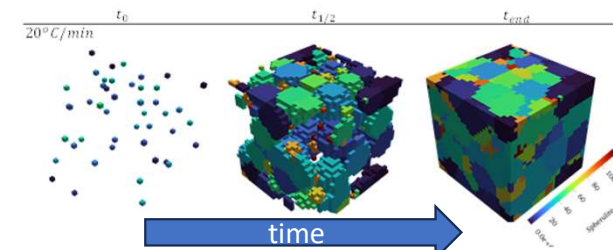
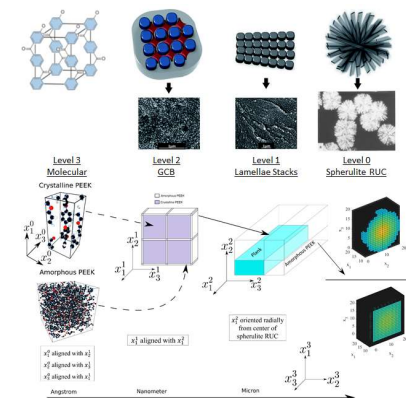
Made progress toward predicting material behavior during welding; leads to better understanding of how welding processes relate to structural performance of welded joints

Multiscale Material Modeling

Objectives: 1) Computational approaches that predict ply mechanical, thermal, and electrical properties as a function of degree of crystallinity. 2) Spherulite growth simulation.

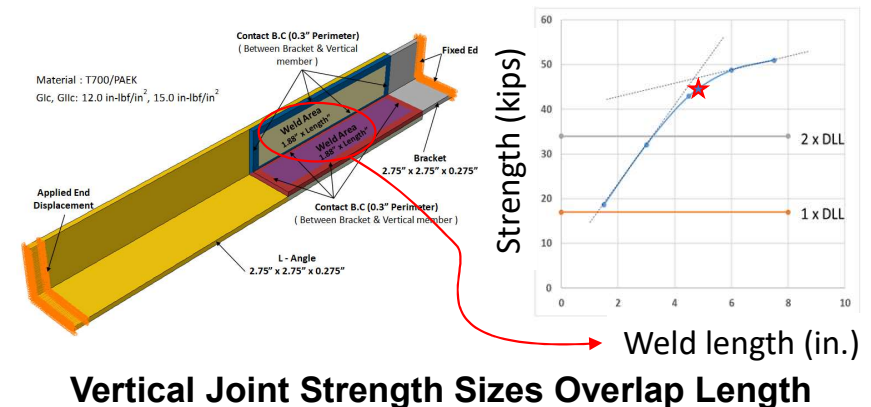
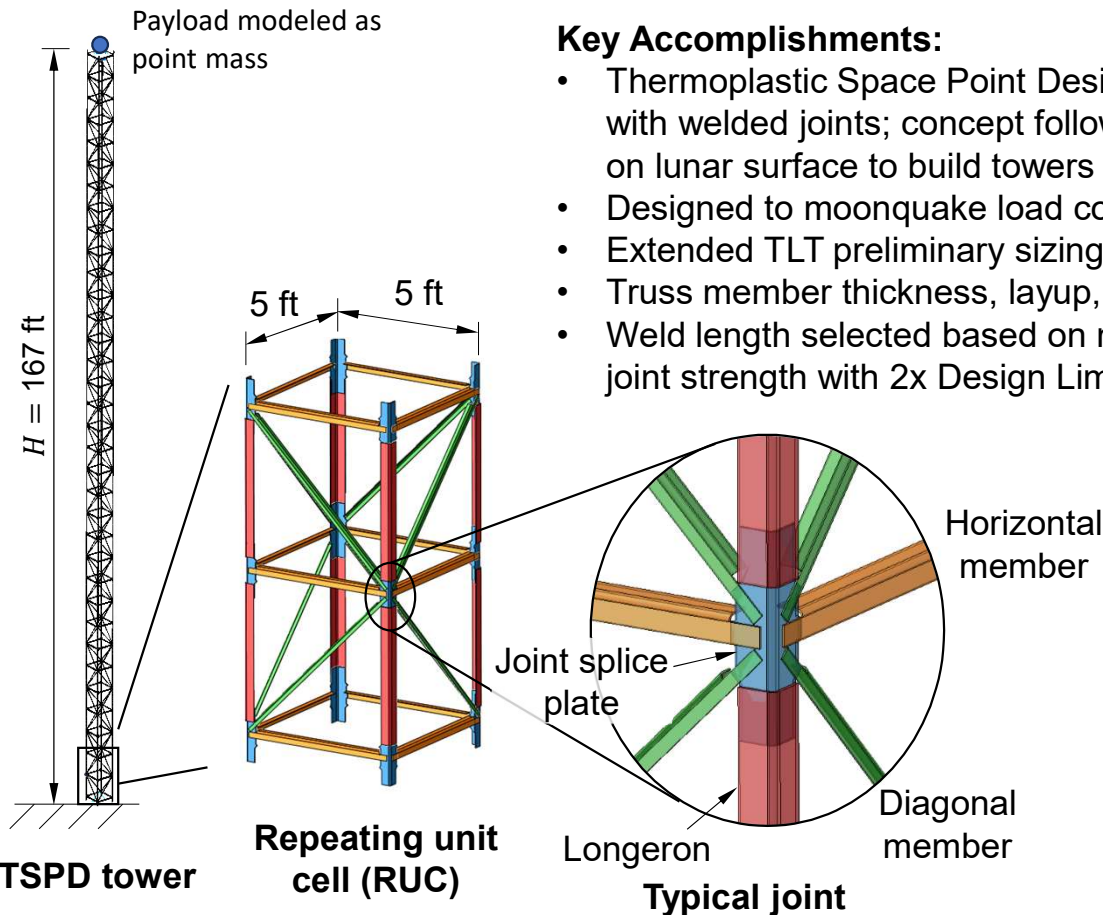
Key Accomplishments:

- Ply properties predicted as a function of crystallinity and fiber volume fraction
- New spherulite growth simulation capability developed. Allows prediction of semi-crystalline microstructures for different manufacturing methods.



Key Accomplishments:

- Thermoplastic Space Point Design (TSPD) is an all-thermoplastic composite lunar tower with welded joints; concept follows Tall Lunar Tower (TLT): assemble structural elements on lunar surface to build towers for power, GNC, and science payloads.
- Designed to moonquake load condition (0.15 moon G harmonic base excitation).
- Extended TLT preliminary sizing tool to include moonquake loads & longeron strength.
- Truss member thickness, layup, and cross-sectional dimensions show positive margin.
- Weld length selected based on maximum load through the joint for positive margin on joint strength with 2x Design Limit Load (DLL).

**Vertical Joint Strength Sizes Overlap Length**

Completed structural design and analysis for 167-ft-tall (50 m) lunar tower concept (TSPD) to use all thermoplastic composite materials and welded joints for assembly

TDEA Accomplishments

TSPD Thermal Analysis

6

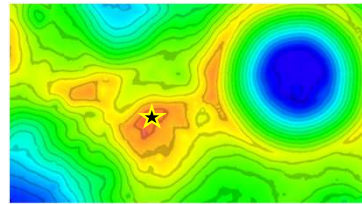


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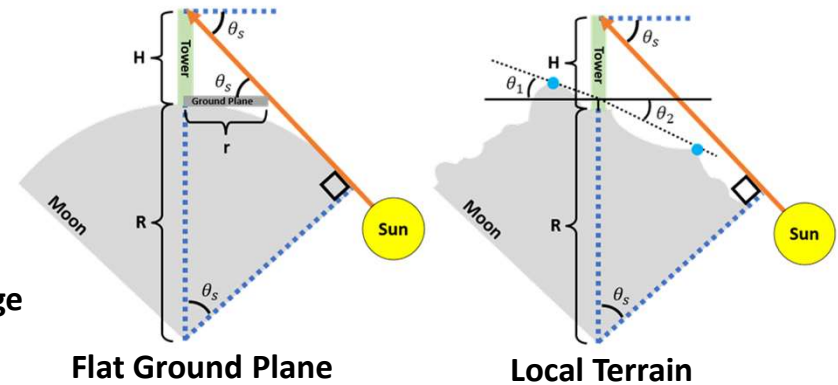
Objective: Identify TSPD temperature extremes and thermal gradients through one year on the lunar surface (south pole) for mechanical loading and informing weld operations.

Key Accomplishments:

- Determined flat ground plane assumption is not adequate for temperature timeline predictions. Terrain impacts surface temperature extremes and trends.
- Predicted tower temperature trends over 1 year.
- Assessed thermal environment for welding: if welding duration < 3 weeks for assembly, welding operations can occur at -70°C.
- Draft NASA TM in review.

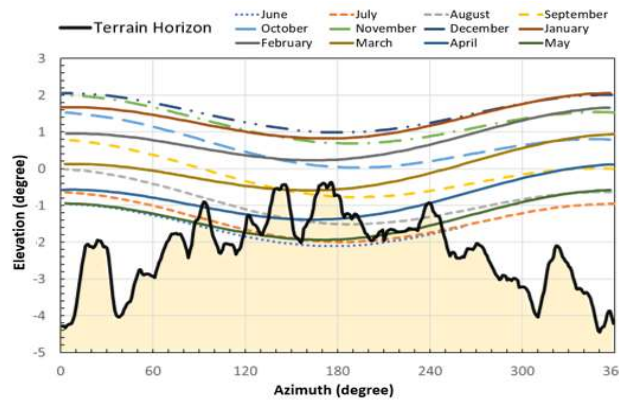


Shackleton Connecting Ridge (Elevation)



Flat Ground Plane

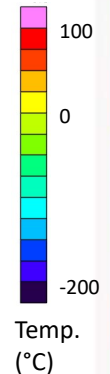
Local Terrain



Calculated Terrain Horizon Plot

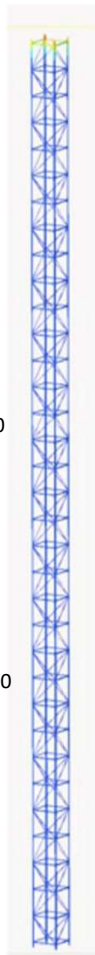


Lunar Surface Temperature Timelapse (13 to 23 days) showing effects of terrain shadowing



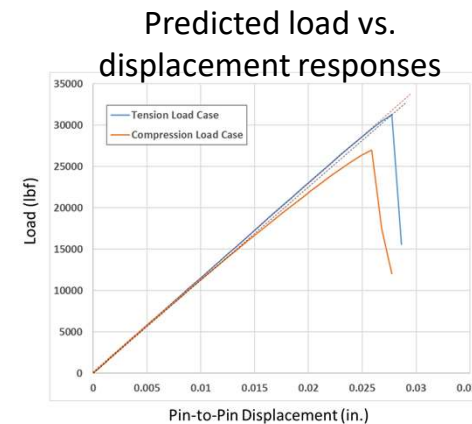
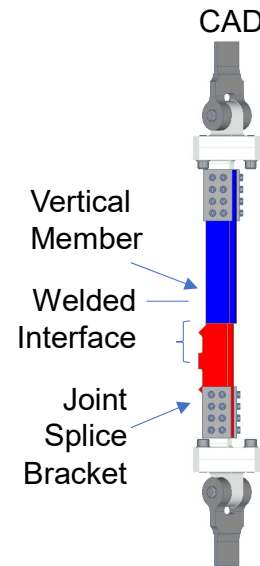
Completed thermal analysis showing the importance of local terrain

Full Tower Timelapse Video (1/2 year)

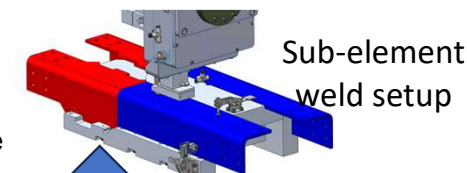
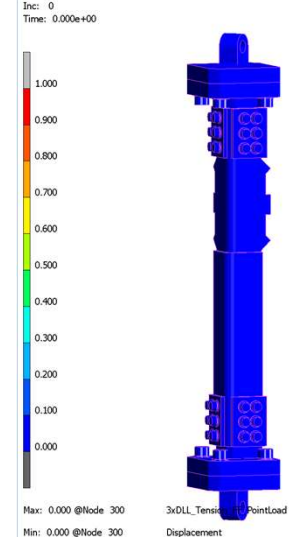


Key Accomplishments:

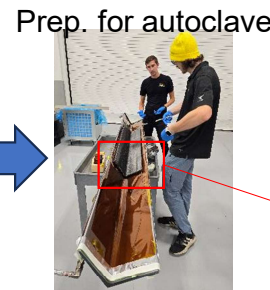
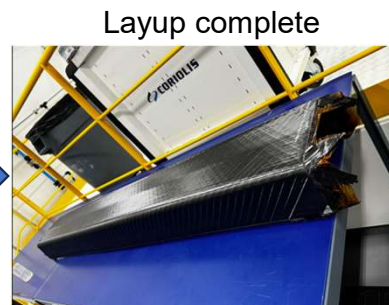
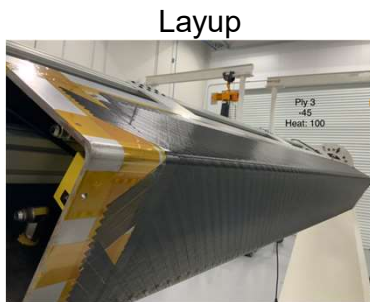
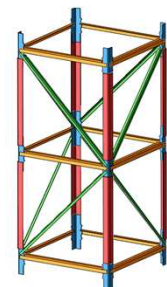
- Designed sub-element test article for most highly loaded joint (vertical).
- Predicted sub-element stiffness and strength for tension and compression load cases; both predicted to fail ~1.5 DLL (based on current weld strength data available from coupon tests).
- Manufacturing structural elements for sub-elements and RUC using automated fiber placement (AFP) system at NIAR (autoclave consolidated).
- Developing ultrasonic weld process through process trials and weld evaluations with Agile Ultrasonics.



Total Displacement (in) Tension



Assemble Repeating Unit Cell (RUC) with ultrasonic welding end-effector on robotic arm



Made progress in manufacturing and preparation for structural tests to substantiate the structural capability of the TSPD



Potential Customers and Infusion Paths

- Human Lander System: Thermal isolators, landing leg, cryogenic tanks, habitat structures.
- Lunar surface infrastructure: Structural elements for construction equipment, pipes/tanks, trusses.
- Advanced manufacturing and On-orbit Servicing, Assembly and Manufacturing: large RF reflectors, space-based solar power, in-space assembled telescope, large transport vehicle backbone.

Next Steps (not funded)

1. Continue developing welding technology for repeatable and controllable temperature/pressure history application.
 - Develop supporting simulation capabilities to streamline process design, analysis, and verification.
2. Build on initial efforts with 5-axis 3D printing with continuous fiber to demonstrate capability.
 - Develop low/zero CTE materials and methods.
3. Pursue thermal vacuum chamber (TVAC) welding trials to mature the welding technology for in-space environments.
4. Integrate down-selected welding approach with in-space robotics and in-line inspection.
5. Develop thermoplastic composite repair technologies for terrestrial and in-space applications.

TDEA Summary



Timer

- Thermoplastic composite technology shows promise for enhancing capability and has applicability to NASA exploration needs.
- Despite getting cut, TDEA accomplished impactful work:
 - Completed over 250 material characterization tests adding to the property database for four commercially available thermoplastic composite materials.
 - Executed a weldability study including over 600 coupon welds with 3 processes and 5 materials:
 - Met KPP-2 for resistance and ultrasonic welding (< 10% CoV strength reliability)
 - Gained new insights: process requirements, potential defects, and performance metrics
 - Advanced models that improve understanding of how welding processes relate to structural performance of welded joints
 - Conducted an initial study of a 5-axis continuous-fiber 3D printing technology – shows promise
 - Completed structural design and analysis for 167-ft-tall (50 m) lunar tower concept (TSPD) to use all thermoplastic composite materials and welded joints for assembly
 - Structural analysis shows positive margin on design
 - Thermal analysis shows the importance of lunar terrain
 - Made progress in manufacturing and preparation for structural tests; to occur in Q1FY25
 - Made progress toward repeating unit cell (RUC) manufacturing demonstration; to occur in Q1FY25