Thermoplastic Composites Conference

Thermoplastics Development for Exploration Applications (TDEA) Project

Programmatic and Technical Overview

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Thermoplastic Development for Exploration Applications (TDEA) Project Overview

Goal:

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.

Objectives:

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

Team:

MSFC (lead),
GSFC,
GRC,
LaRC

Budget:

$10.5M, FY22-24

Game Changing Development Program

Why Thermoplastic Composites?

Qualitative comparison of thermoplastic composites (TPC) and thermoset composites (TSC)

Advantages:

- Reduced cycle time
- **Processing by remelting**
- Automated assembly (robotic welding)
- **Higher fracture toughness**
- **Ambient storage, no shelf life**
- **Welded joints with no material interface**
- **Processing that enables unitization**
- **Minimal outgassing**
- Low moisture uptake

Disadvantages:

- **Higher processing temperature and pressure required**
- **Higher residual stresses (more difficult dimensional control)**
- Higher raw material cost
- Structural and chemical properties sensitive to crystallinity
- Higher melted viscosity
- Crystallinity may change over lifecycle
- Lower TRL

Bolded characteristics especially relevant for space applications

Selected property comparison

Property	TPC T700/LM PAEK[b]	TSC IM7/8552[a]
Density, ρ	1.6 g/cm3	1.6 g/cm3
Glass transition temperature[c], T_g	147°C	200°C
Transverse stiffness, E_{22}	9.1 GPa	8.7 GPa
Transverse tensile strength[d], Y_T	94 MPa	80 MPa
Interlaminar toughness, G_{1c}	2.1 kJ/m^2	0.24

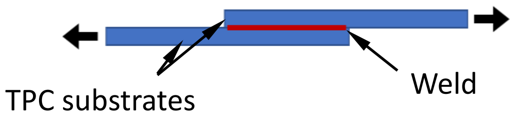
[a]Wanthal, et al., ASC Conference, 2017
[b]NCAMP database, report CAM-RP-2019-036 RevA
[c]Neat resin, dry, from manufacturer's datasheet
[d]ASTM D3039

Recommendations: High Priority TPC Developments for Space Applications

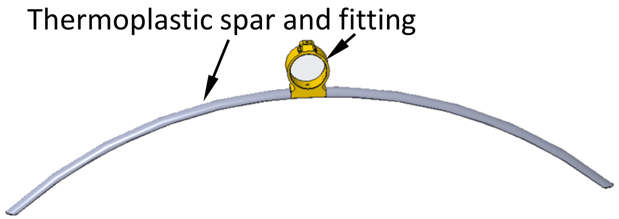
	Recommendation	Objectives	TDEA Contribution
1	Launch vehicle structure trade study: TSC vs. TPC	• Quantify the weight and costs savings for TPC compared to SoA TSC baseline. • Characterize the applicability of TPCs for launch vehicle cryotanks.	Preliminary assessment of weight savings with postbuckled TPC design.
2	TPC material qual. for space applications	• Generate space-relevant material properties for candidate TPC materials to support future trade studies and PDR level analysis.	Laminate mechanical performance: AS4/PEEK, AS4/PPS, T700/LM PAEK, AS4/PEI (additional mat'ls and tests TDB)
3	Demonstrate capability for TPC welded joints (flat coupons)	• Confidence in TPC welded joint design, sizing, and fabrication at the coupon scale. • Analysis tools and relevant experience to assess welding methods for terrestrial and in-space assembly (ISA). • Characterization of joint behavior in off-nominal environments.	Welded joint pathfinder study
4	Evaluate cost & benefits for low-production-volume TPC parts	• Demonstrate cost-effective materials, process, and structural performance for specialized space application structures (currently made with TSC or metals).	Roman Space Telescope (RST) Deployable Aperture Cover (DAC) 'conceptual' TPC support beam
5	De-risk TPC manufacturing, design, analysis, and inspection technology for in-space construction	• Ground test data for evaluation of ISA with TPCs. • Validated process monitoring and modeling for high-confidence in-space operations. • Tool-less TPC AFP technologies suitable for in-space construction of pressure vessels.	Element/subcomponent test and analysis for ISA using TPCs

TDEA Technology Roadmap

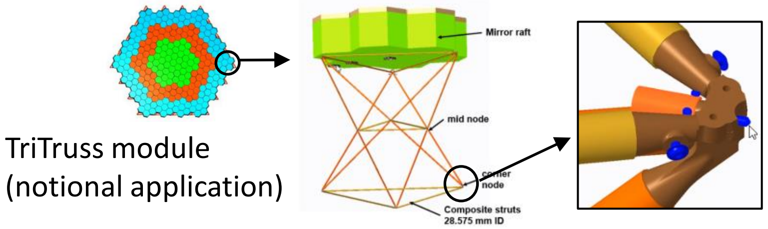
Welded joint pathfinder
Foundational developments



Roman Space Telescope (RST) support beam
Confidence building application



Game Changing application
Developments for in-space TPC truss assembly



What?

Welded joint pathfinder:
- Coupon scale, **single welded interface**
- Develop analysis approaches for welded joints trade studies
- Fabricate and test joints with nominal conditions, and conditions relevant to in-space applications (e.g., off-nominal thermal history, lunar dust contamination)

RST support beam:
- Moderate-scale, **single spar and fitting**
- Terrestrially manufactured and assembled spacecraft structure
- Evaluate approaches that reduce cost through reduced part count and complexity compared with the RST baseline design

Game Changing application:
- Large-scale, **multiple spars and fittings**
- Terrestrially manufacturing and in-space assembly (ISA)
- Identify relevant welded joint design requirements, and establish a TDEA Point Design
- Demonstrate through the building block approach

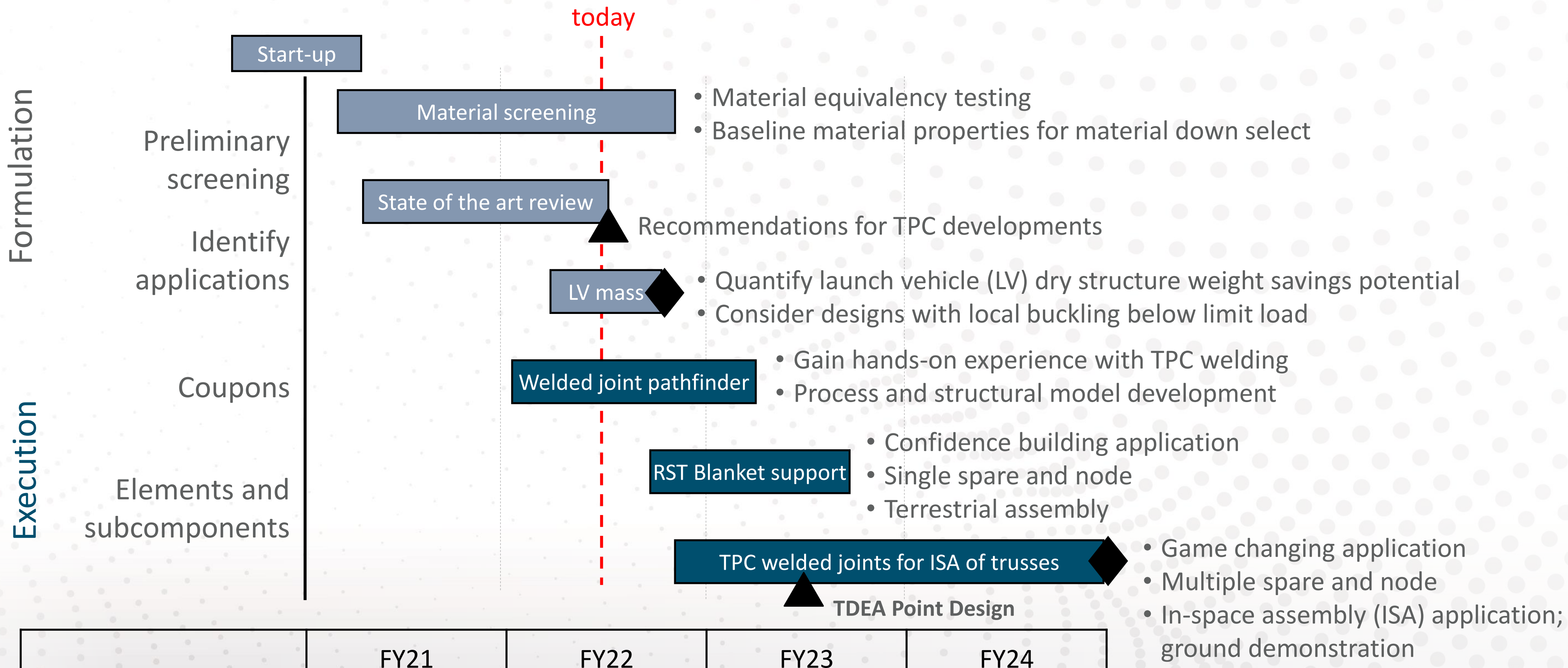
Why?

Welded joint pathfinder:
- Seek in-house capabilities for TPC welding relevant to space applications
- Simple generic configuration to leverage existing data

RST support beam:
- Knowledge gap in application of TPCs to low-production-volume applications
- How can processes unique to TPCs (e.g., welding, additive) enable better designs?

Game Changing application:
- Challenges remain for TPCs use in ISA/OSAM
- Develop deep understanding of considerations for TPC joining in-space

TDEA Planned Activities and Schedule



	FY21	FY22	FY23	FY24
FY21 Budget Request	Worked as part of CTE project	$2M	$3.5M	$5M
Civil servant FTE		9	10	10

High-Rate Composites for Aircraft Manufacturing

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Thermoplastics Composites Conference
San Diego, CA

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Sponsored by American Composites Manufacturing Association (ACMA)

Outline

- **Motivation: Projected Transportation Needs**
- **High-Rate Composites Aircraft Manufacturing (HiCAM) Project Objectives and Approach**
- **Preliminary HiCAM Thermoplastic Automated Fiber Placement (TP-AFP) Results**

Composite Transport Market Demand and Opportunity

- **The global aviation system of 2040 is emerging today – new companies and new systems built on advanced technologies, many with "NASA DNA" and enabled by steady U.S. industry investment.**

Boeing & Airbus market outlook:

- **By 2040, > 43,000 deliveries**
  - replace 80% current & double fleet size
  - single-aisle, 2nd decade demand ~150 per month

Historic aircraft production rates per month:

• Metals (B737, A320) :	60	1.3x = 80
• Composites (B787, A220) :	10-14	6x = 80

Increased Emphasis on Sustainability:

- Reduced emissions (weight, drag)
- Reduced operating costs (fuel, acquisition, maintenance)

Market drivers: earlier deliveries (high production rate), cost reductions & performance improvements.

NASA High-rate Composites for Aircraft Manufacturing (HiCAM)

NASA, US Industry, and Universities have partnered in the Advanced Composites Consortium (ACC) to respond to these challenges and to deliver the desired outcomes with the following understanding:

Not plausible to scale current composites production system 6x:

- **Supply chain: limited skilled labor and specialized equipment; Difficult to ramp and adjust with demand**
- **Scaling current composites production doesn't reduce acquisition cost**
- **Technology needed to improve production efficiency (increasing rate, while reducing cost)**
- **Requires more efficient use of manufacturing factory footprint**

Continuing to advance aviation in 2040 and beyond … requires new capabilities for rapid manufacturing:

- **Future production rates require improvements and streamlined relationships in aircraft design, materials, certification and manufacturing methodologies**
- **Design, certification and manufacturing are inseparable and must be considered together early in the aircraft conceptualization process.**

NASA HiCAM Project : Composites Manufacturing Focus Areas

Based on a NASA and industry workshop on advanced manufacturing[1] held in 2018 and subsequent discussions with the FAA and the ACC partners to assess the state of the art of rapid/advanced manufacturing, the following industry technology needs and proposed NASA investments were identified:

Topic of Technical Presentation today

- **Non-Destructive Inspection (NDI)**
- **Rapid Cure Infusion Resins**
- **Stitched Resin Infusion**
- **Thermoplastic Forming**
- **Thermoplastic Assembly**
- **Thermoplastic Automated Fiber Placement (TP-AFP)**
- **Next Generation (Rapid) Thermoset AFP and Cure**
- **Validated Process Model Software Tools**
- **Validated Progressive Damage Analysis (PDA) Model Software Tools**
- **Design For Manufacturing (DFM) Software Tools**

In addition to the technology insertion points listed , NASA, Boeing and Spirit are conducting trade studies with a baseline design in to identify the technologies to develop to reach the 6X goal of composite wing and fuselage ship-sets per month.

[1]Reference: J. B. Ransom, E.H. Glaessgen, and B.J. Jensen: “ARMD Workshop on Materials and Methods for Rapid Manufacturing for Commercial and Urban Aviation.” NASA/TM–2019-220428; DOI: 20200000067

Current ACC partners in HiCAM Project

- NASA
- ATC Manufacturing
- Boeing
- CGTech
- Collier Research
- Electroimpact
- GE Aviation
- Hexcel
- Northrup (NGSC)
- Rohr (Collins/RTX)
- Solvay
- SPIRIT
- Toray
- University of South Carolina (McNair)
- Wichita State University (NIAR)

HiCAM Requirements, Performance Metrics and Success Criteria

Requirements:

1. Airframe components shall comply with Airworthiness Standards required for aircraft certification

2. Maturity: technology readiness level (TRL) and manufacturing readiness level (MRL)

a) Manufacturing technologies matured to TRL 6, MRL 6 by Project Closeout

b) Related Model based engineering (MBE) tools matured to TRL 6 by Project Closeout

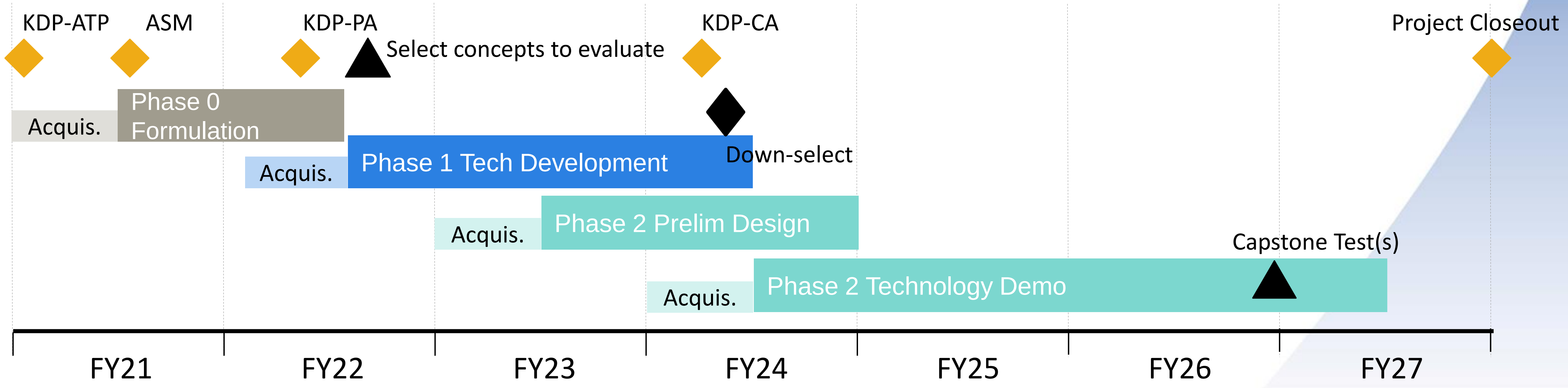
Performance Metrics:

KPP	HiCAM Full Success	HiCAM Min Success
Composite Production Rate	80 Shipsets per Month	60 Shipsets per Month
Component Net Cost per Shipset	Cost Reduction > 50% of Baseline	Cost Reduction > 30% of Baseline
Component Weight	>2% lighter than baseline	<2% Heavier than Baseline
MBE Tool Accuracy	Predicts Experimental Values within Stakeholder-defined Tolerance	Simulates Experimental Trends

Capstone demonstration will anchor and validate technology models that show ~80 aircraft a month is achievable with cost and weight reductions.

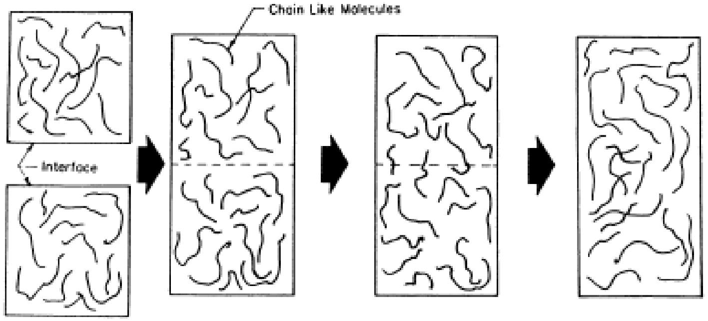
HiCAM and the Advanced Composites Consortium

- **Membership of ACC established based upon qualifications and selection criterion**
- To develop/award collaborative tasks performed by NASA and members of the ACC:
  - Project Technology Development Areas (Topics) identified with ACC partner input and listed on previous slide
  - Project issues request for proposals (RFPs) for specific Topics; NASA & partners form Cooperative Research Teams (CRTs), propose Project Work Plans (PWPs)
  - PWPs reviewed/approved by ACC managing committees; NASA-only detailed cost and technical review
- HiCAM Project Manager- NASA LaRC Dr. Rick Young decides which PWPs to fund; NASA issues cooperative agreement contracts to partners... Funding of CRT approved work: NASA matches the IRAD funds of the ACC partner minus a small contract admin fee



Thermoplastic Composites Automated Fiber Placement

- Thermoplastic matrix composites have high potential in rapid manufacturing because of inherently low process cycle times

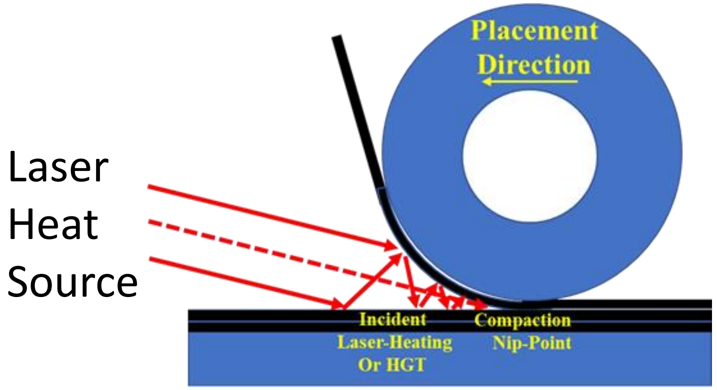


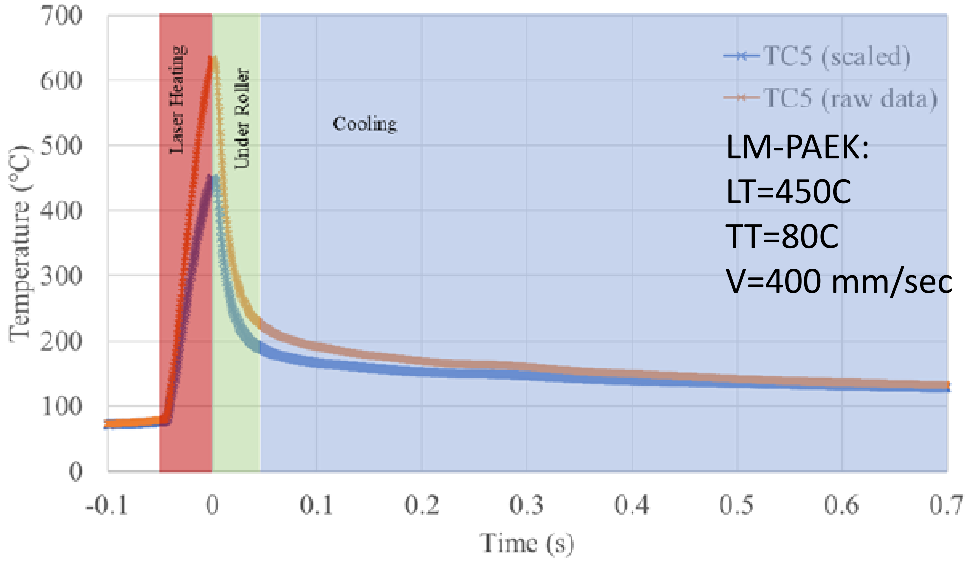
Initial Contact **Partial Diffusion** **Cofusion**

Thermoplastic Fusion-Bonding (Autohesion) Phenomenon[2]

CF/Thermoplastic tape plies consolidate into a laminate by fusion bonding at the interfaces.

- The interfacial bond strength is a function of the processing temperature, contact pressure, and contact time.
- Interfacial bond strength increases with time due to interdiffusion of mobile molecular chain ends across the interface.
- After intimate contact, interpenetration and re-entanglement of the polymer chains occurs and ultimate cohesive strength is achieved.



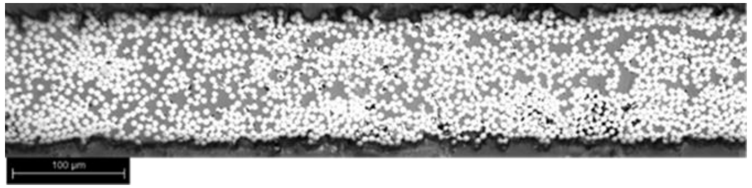


In-situ Consolidation AFP of Thermoplastics (ICAT) Process Temperature Cycle

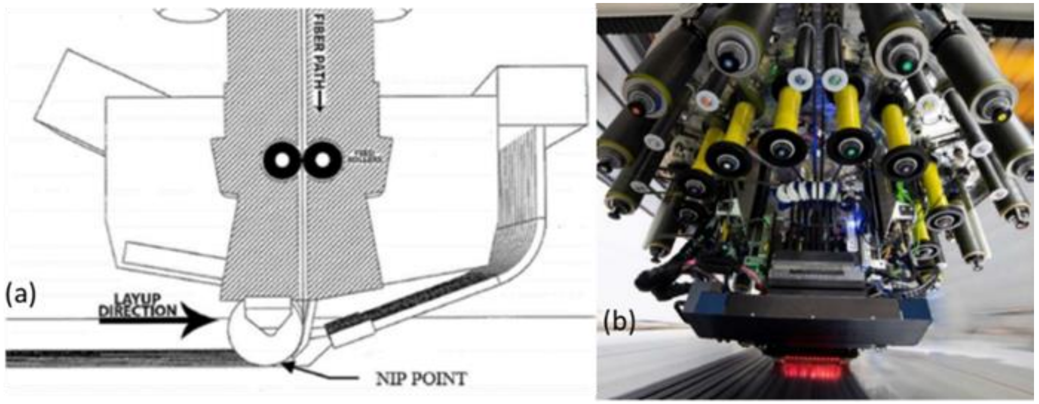
[2]Reference: A.C. Loos and P.H. Dara: "PROCESSING OF THERMOPLASTIC MATRIX COMPOSITES." NASA/Contractor Report–NASA Grant NAG1-343; DOI: 10.1007/978-1-4613-1893-4_143

NASA ICAT Processing Trials with Electroimpact, Inc.

- During this first year of the HiCAM project NASA has partnered with SPIRIT, Raytheon, Electroimpact, and NIAR on the quantitative assessment of In-situ Consolidation AFP of Thermoplastics (ICAT), which is TP-AFP without any oven or autoclave post-consolidation steps; In ICAT: Intimate contact, autohesion and crystallization all occur during the placement process on heated tooling.
- NASA and Electroimpact ICAT Process Assessment:



Toray TC1200 T800/PEEK; 145gsm, 34% RC slit tape; T_M=343°C



Electroimpact VSS-HP Laser system concept (a) and Image of EI 16-tow head (b) placing 0.25” tapes [8] during ICAT trials [3]

Victrex LM-PAEK IM7/AE250; 148gsm, 34% RC slit tape; T_M=309°C

[3]Reference: B.W.Grimsley, et.al.: “IN-SITU CONSOLIDATION AUTOMATED FIBER PLACEMENT OF THERMOPLASTIC COMPOSITES FOR HIGH-RATE AIRCRAFT MANUFACTURING,” SAMPE Conference and Exposition, 2022

Results of NASA ICAT DoE: Toray TC1200 PEEK

- ICAT processing DoE at Electroimpact varying Laser Target Temperature (LT), Tool Temperature (TT) and Placement Speed (V) for two 0.25” slit-tape materials:

LT=400°C, TT=80°C, V= 170 mm/sec (402 in/min)*

LT=450°C, TT=120°C, V= 250 mm/sec

LT=500C, TT=120C, V= 400 mm/sec (945 in/min)

Poor Contact (red arrows)

Process Recipe Selected for SBS test panel

LT=400°C, TT=120°C, V= 250 mm/sec (591 in/min)

LT=500C, TT=80C, V= 250 mm/sec

LT=500C, TT=120C, V= 100mm/sec (236 in/min)

Results of NASA ICAT DoE: Victrex IM7/AE250 LM-PAEK

LT=350°C, TT=80°C, V= 170 mm/sec (402 in/min)

Poor Contact (red arrow)

LT=450°C, TT=120°C, V= 250 mm/sec

LT=400°C, TT=120°C, V= 250 mm/sec (591 in/min)

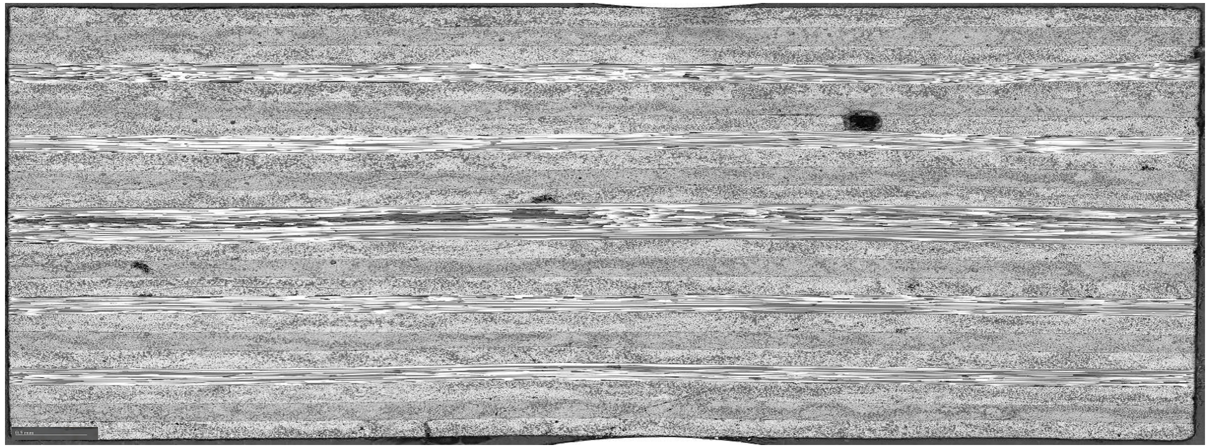
LT=450°C, TT=80°C, V= 250mm/sec

Process Recipe Selected for SBS test panel

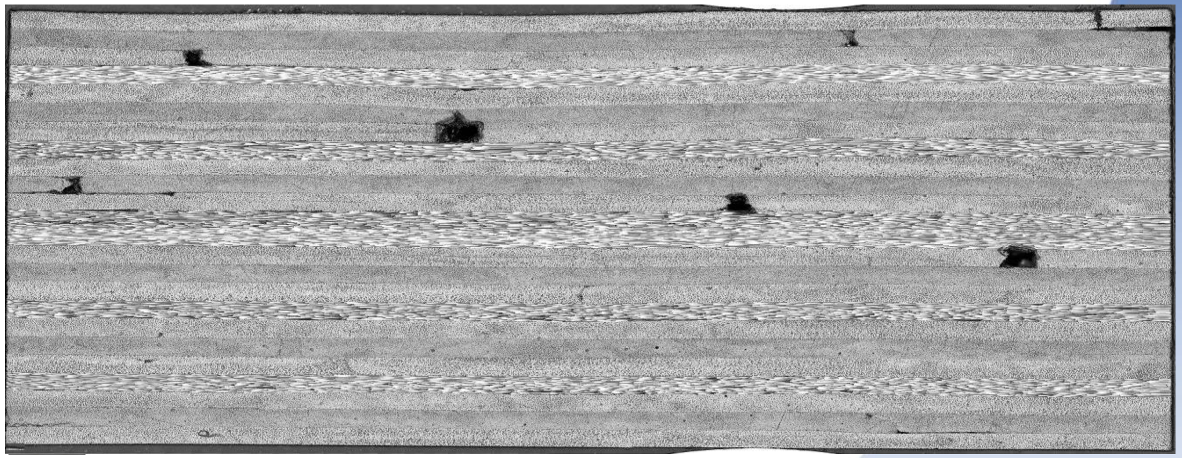
LT=450°C, TT=80°C, V= 400mm/sec (945 in/min)

ICAT SBS Test Panels

- Using the ICAT process parameters identified in the abbreviated DoE, one PEEK panel and one LM-PAEK panel were fabricated with quasi lay-up: $[45^O/0^O/-45^O/90^O]_{3S}$ After ICAT processing the resulting panels were cut into three sections using a wet-saw resulting in:
  - PEEK and LM-PAEK ICAT panels
  - PEEK and LM-PAEK ICAT + Vacuum-Bag Oven (VBO) post consolidation panel
  - PEEK and LM-PAEK ICAT + Autoclave post-consolidation panel
- ASTM D2344 testing is in progress of the SBS coupons from these panels.



ICAT Fabricated PEEK Panel



ICAT Fabricated LM-PAEK Panel

Summary

- The new Variable Spot Size, High Power (VSS-HP) laser heating system developed by Electroimpact is capable of heating the surfaces of the PEEK and PAEK tapes to the target temperatures of up to 500^{O}C at speeds up to 400mm/sec (945in/min)
- Based on photo-microscopy of the panels fabricated, it appears that intimate contact was established for the CF/ Poly(aryrletherketone) thermoplastic materials during ICAT:
- PEEK tape at LT=500^{O}C, TT= 120^{O}C, and V=100 mm/sec
- LM-PAEK tape at LT=450^{O}C, TT=80^{O}C, and V= 400 mm/sec

- The degree of fusion-bonding (consolidation) at these processing conditions will be determined by SBS testing… currently in progress

Questions?