Composite Manufacturing and Process Monitoring for Space and Aeronautics Applications

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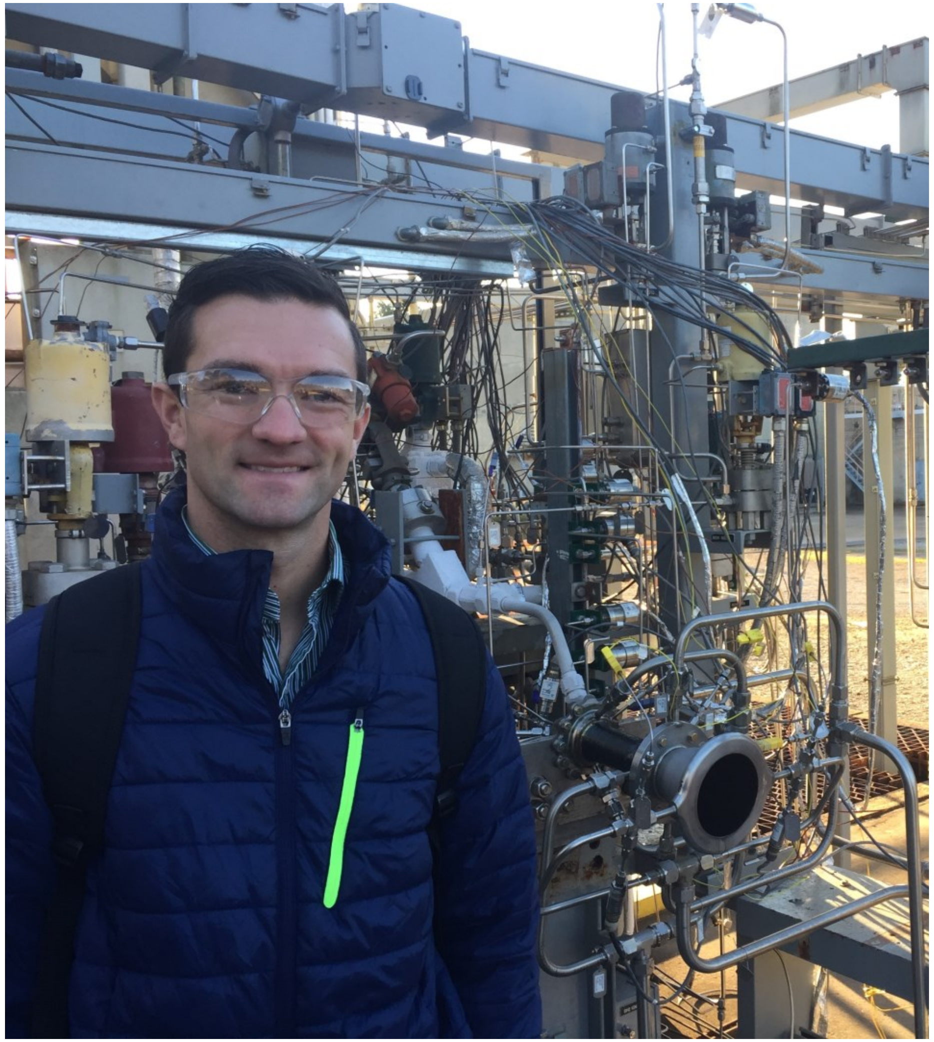
Outline

- ❖ Personal Introduction
- ❖ Projects
  - ❖ Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)
  - ❖ AERoBOND: Incubation to Major NASA Aeronautics Projects
  - ❖ Cure Process Monitoring of Composites
- ❖ Summary
- ❖ Questions

About Me

❖ Current Position:
  - ❖ NASA Langley Research Center (2018-Present)
  - ❖ Senior Materials Research Engineer, Advanced Materials and Processing Branch, Research Directorate
  - ❖ Research focus: Manufacturing and process monitoring of advanced aerospace composite structures

❖ How did I get here?
  - ❖ Graduate Research Assistant, National Institute of Aerospace (NIA), 2013-2017
    - ❖ Research performed on-site at NASA LaRC, 2014-2017
  - ❖ Internships: Boeing, Caterpillar, Duke Energy, Progress Energy
  - ❖ Education:
    - ❖ Ph.D. Aerospace Engineering, N.C. State University, 2017
    - ❖ M.S. Mechanical Engineering, N.C. State University, 2014
    - ❖ B.S. Civil Engineering, N.C. State University, 2012



Personal Spotlight

Exciting Times at NASA

Artemis

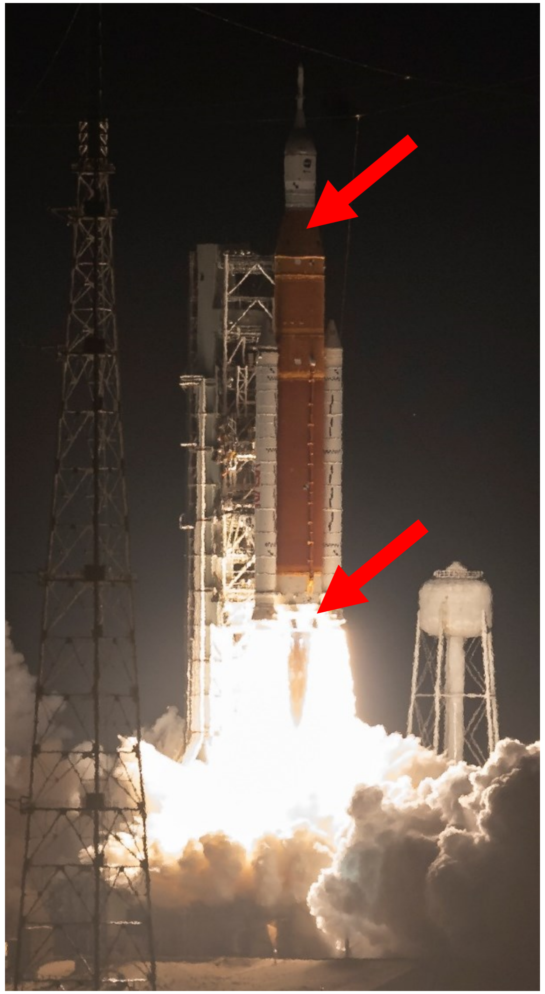


Image Credits: NASA/Bill Ingalls
https://www.nasa.gov/press-release/liftoff-nasa-s-artemis-i-mega-rocket-launches-orion-to-moon

Commercial Crew

Image Credit: NASA
https://www.nasa.gov/news-release/nasa-tv-to-air-first-us-commercial-crew-port-relocation-on-space-station/

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https://www.nasa.gov/news-release/nasa-invites-media-to-first-astronaut-launch-aboard-boeings-starliner/

X-Planes

Image Credit: NASA
https://www.nasa.gov/image-detail/transforming-aviation-2/

Image Credit: NASA
https://technology.nasa.gov/patent/TOP2-313

Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

1. A.M. Clark, T.B. Hudson, C. Park, S.G. Miller, M. Goetz, and P.R. Gradl, "Composite overwrap lessons learned on 40k thrust chamber assemblies," *To be published in SAMPE Technical Conference Proceedings,* Seattle, WA, April 17-20, 2023.
2. A.M. Clark, T.B. Hudson, S.G. Miller, C. Park, C.S. Protz, "Lightweight thrust chamber composite overwrap lessons learned," *Composites and Advanced Materials Expo (CAMX) Proceedings,* Dallas, TX, October 19-21, 2021.
3. P.R. Gradl, C.S. Protz, J. Fikes, A. Clark, L. Evans, S. Miller, D. Ellis, and T.B. Hudson, "Lightweight thrust chamber assemblies using multi-alloy additive manufacturing and composite overwrap, *AIAA Propulsion & Energy Forum Proceedings,* New Orleans, LA, August 24-26, 2020.

Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

- ❖Mature novel design and manufacturing technologies to ***increase scale***, significantly ***reduce cost***, and improve performance for ***regeneratively-cooled thrust chamber assemblies***
  - ❖Highest-cost and longest-lead components on rocket engines
- ❖Five Key Technologies:
  1. Powder bed fusion copper combustion chamber
  2. Freeform blown powder nozzle
  3. ***Composite overwrap structural jacket***
  4. Bimetallic radial deposition for manifolds
  5. Modeling and analysis tools for additive manufacturing and regeneratively-cooled designs

Hardware Overview

$2k\text{-}lb_f$ Thrust

Fuel Type: LOX/RP-1 and LOX/LH_2

Decoupled Chamber

Coupled Chamber

Engine Class: Reaction Control Thrusters

$7k\text{-}lb_f$ Thrust

Fuel Type: LOX/LCH_4

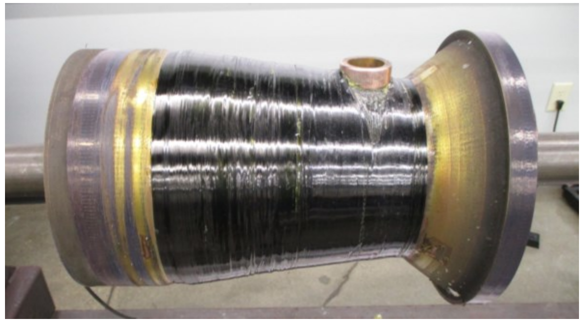
Decoupled Chamber

Coupled Chamber

Engine Class: Lunar (and Planetary) Landers

$40k\text{-}lb_f$ Thrust

Fuel Type: LOX/LH_2



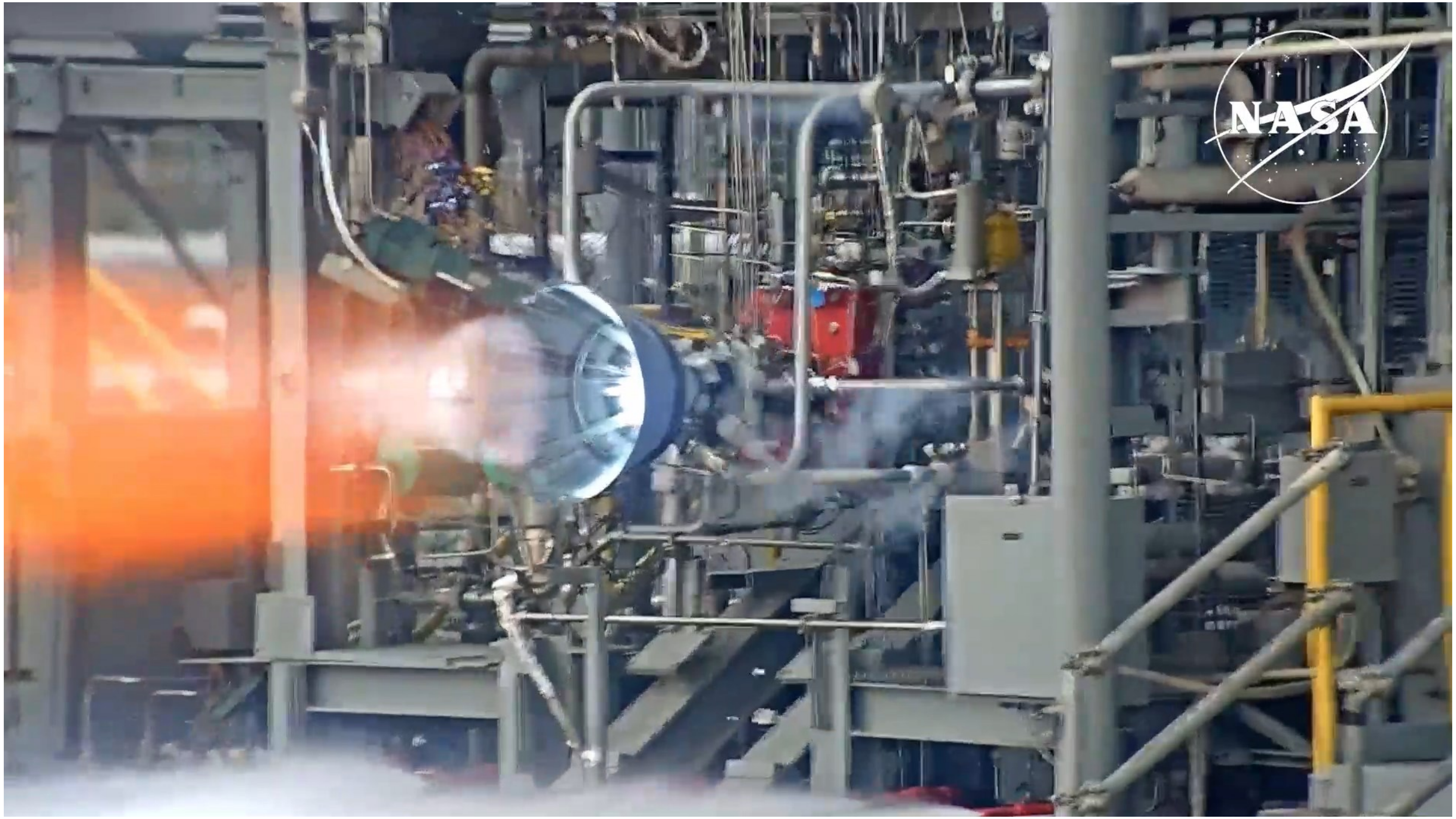
Decoupled Chamber

Coupled Chamber

Engine Class: Launch Vehicle (Upper Stage)

LOX: Liquid Oxygen
RP-1: Rocket Propellant-1 (highly refined form of kerosene)
LH_2: Liquid Hydrogen
LCH_4: Liquid Methane

Hot Fire Test Video:
40k-lb_f Thrust with LOX/LH_2



AERoBOND: Incubation to Major NASA Aeronautics Projects

1. F.L. Palmieri, T.B. Hudson, A.J. Smith, R.J. Cano, J.H. Kang, Y. Lin, L.J. Abbot, B. Clifford, I.J. Barnett, and John W. Connell, "Latent cure epoxy resins for reliable joints in secondary-bonded composite structures," *Composites Part B: Engineering*, Vol. 231, p. 109603, 2021. https://doi.org/10.1016/j.compositesb.2021.109603
2. A.J. Smith, J.A. Salem, T.B. Hudson, and F.L. Palmieri, "Interlaminar mechanical performance of the latent-cure epoxy joint," *Composites Part B,* Vol. 255, 110567, 202. https://doi.org/10.1016/j.compositesb.2023.110567
3. T.B. Hudson, F. Baro, A.J. Smith, and F.L. Palmieri, "Ultrasonic inspection during autoclave cure of reflowable-interface composite joints," *Journal of Composite Materials,* Vol. 57(22), pp. 3515-3528, 2023. https://doi.org/10.1177/00219983231188173
4. T.B. Hudson, F. Baro, A.J. Smith, and F.L. Palmieri, "Offset-stoichiometric reflowable composite bonding method with adhesive for mitigating strict faying surface tolerances," *In-Press*, 2024.

Single-Aisle Commercial Transport Aircraft

Airframes are assemblies of many parts

- ❖Composites can be assembled rapidly with adhesives
- ❖Redundant load path (bolts) is required for certification
- ❖**Thousands of drilling and installation steps**
- ❖Fastener installation is **too slow** causing a bottleneck
- ❖Production rates cannot meet future demand

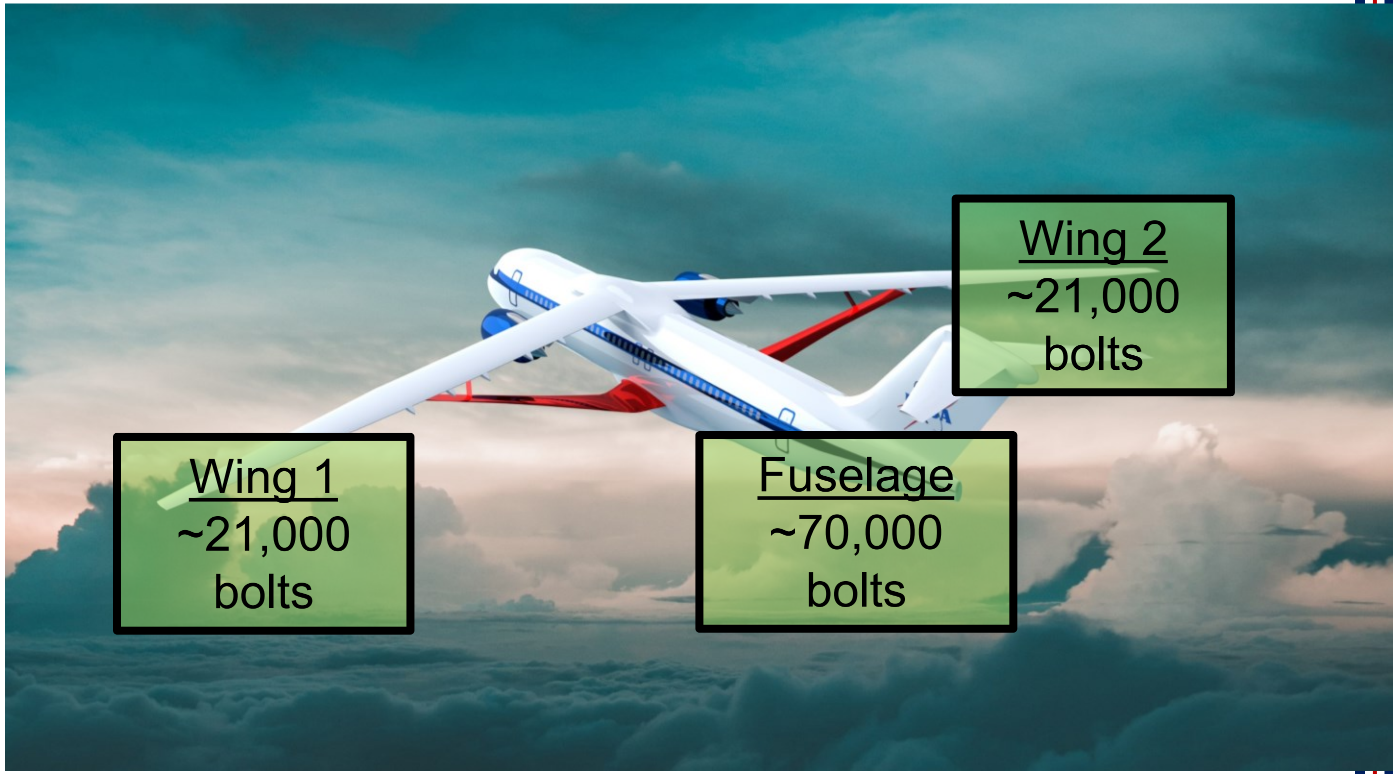
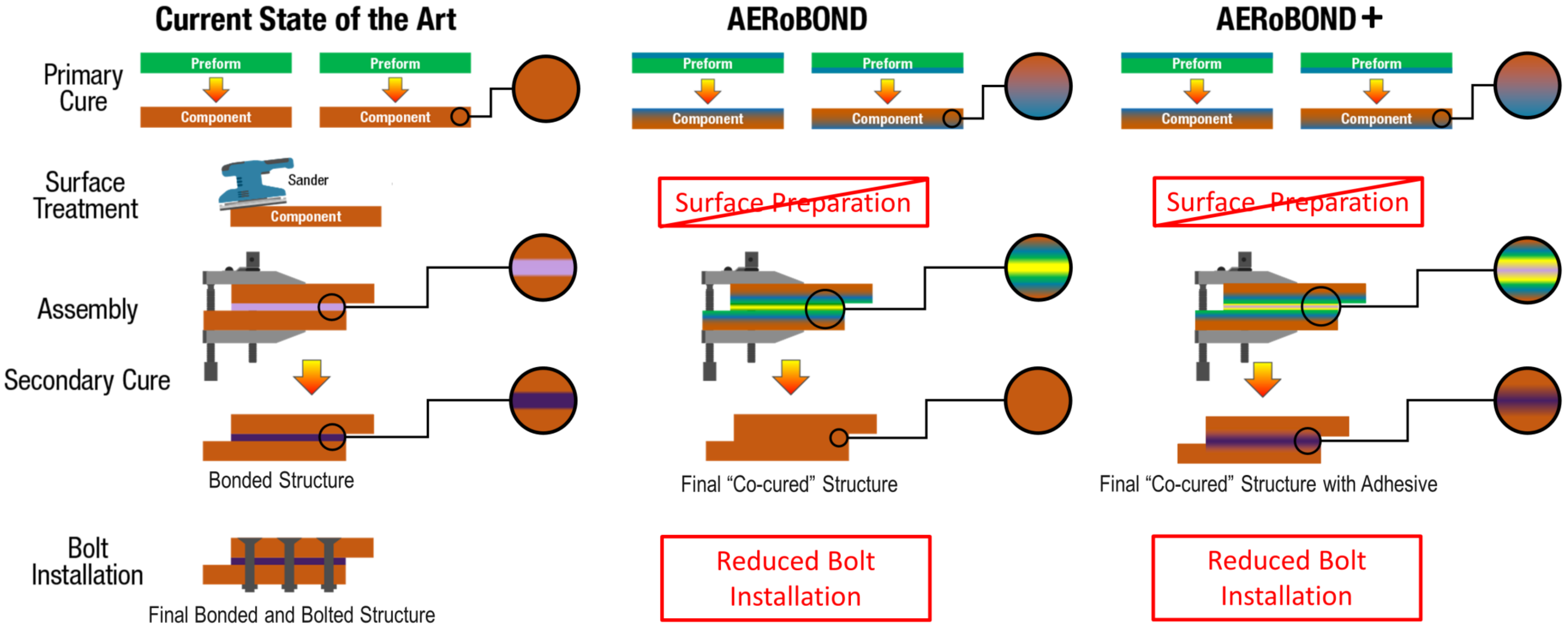
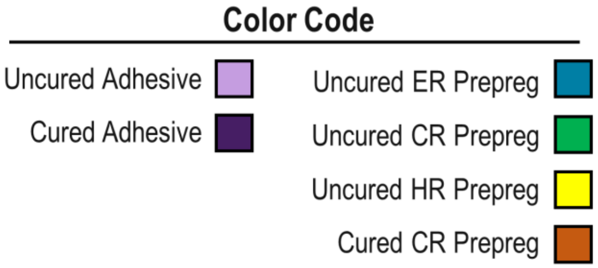


Image Credit: NASA
https://www.nasa.gov/sites/default/files/thumbnails/image/ttbw-3-4-back-left.jpg

What is AERoBOND/AERoBOND+?





AERoBOND/AERoBOND+: Enabling Reliable and Rapid Manufacturing for Tomorrow's Aircraft

Why is AERoBOND Transformational?

AERoBOND addresses part of the production bottleneck

- ❖Eliminates need for surface preparation
- ❖Significantly reduces reliance on redundant fasteners
- ❖Faster assembly than state-of-art (SoA)
- ❖Equivalent or improved mechanical properties to SoA
- ❖AERoBOND+ alleviates tight fit-up tolerances of AEROBOND
- ❖AERoBOND+ is drop-in replacement for existing adhesively-bonded joint designs

AERoBOND Development

- ❖Internal Research and Development (IRAD), Convergent Aeronautics Solutions (CAS), bridge funding by CAS/SUSAN, evaluation in High-rate Commercial Aircraft Manufacturing (HiCAM), and assembly method for SWEET-15 (Structural Wing Experiment Evaluating Truss-bracing - 15ft) ground test article
- ❖Technology patented (1 patent/1 patent application) and licensed by material supplier
- ❖Development of commercial supplier through Tech Transfer office and Space Act Agreement (SAA)

Cure Process Monitoring of Composites: Prototype to Capability

1. T.B. Hudson, P.J. Follis, J.J. Pinakidis, T. Sreekantamurthy, and F.L. Palmieri, "Porosity detection and localization during composite cure inside an autoclave using ultrasonic inspection," Composites Part A: Applied Science and Manufacturing, 106337, 2021. https://doi.org/10.1016/j.compositesa.2021.106337
2. T.B. Hudson, N. Auwaijan, and F.G. Yuan, "Guided wave-based system for real-time cure monitoring of composites using piezoelectric discs and fiber Bragg gratings/phase-shifted fiber Bragg gratings," Journal of Composite Materials, Vol. 53, pp. 969–979, 2019. https://doi.org/10.1177/0021998318793512
3. T.B. Hudson and F.G. Yuan, "Automated in-process cure monitoring of composite laminates using a guided wave-based system with high temperature piezoelectric transducers," Journal of Nondestructive Evaluation, Diagnostics and Prognostics of Engineering Systems, Vol. 1, paper no. 021008, 2018. https://doi.org/10.1115/1.4039230

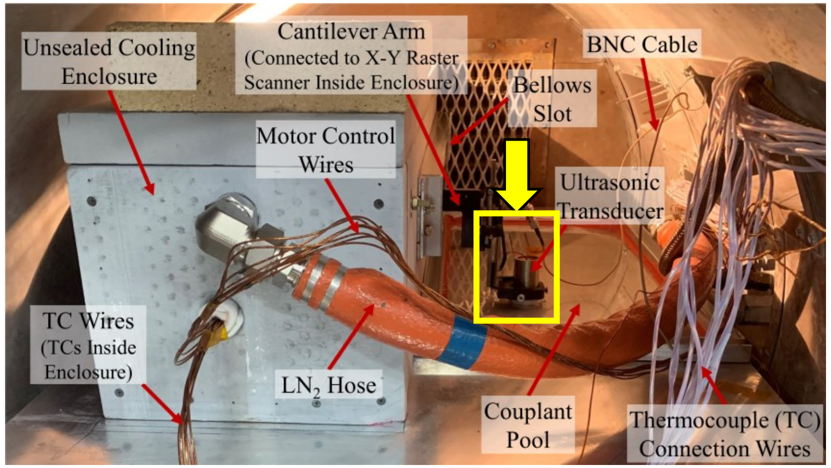
Challenge

- ❖ Composite materials offer many advantages to aerospace applications
- ❖ Defects (e.g., porosity) occur during the manufacture of composites
- ❖ No direct measurement technique of defects during cure existed
  - ❖ State-of-art (SoA) inspection processes did not occur until after cure. If defects are present, expensive rework is required (up to scrapping the part).

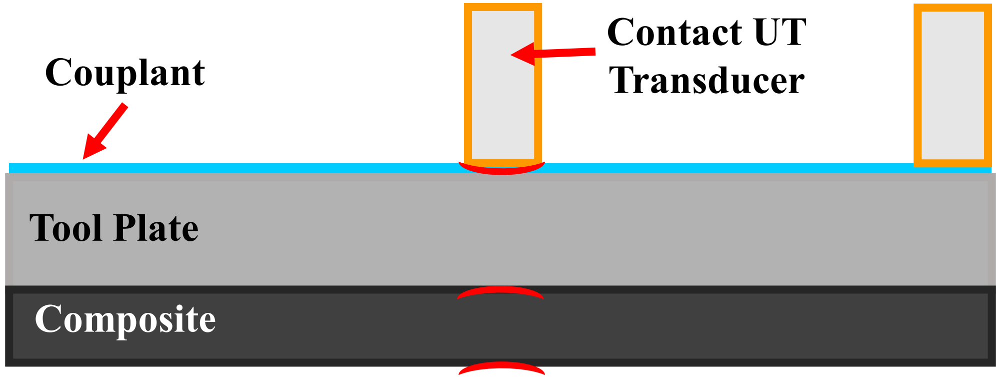
Optical Micrographs Detailing Moderate (left), Low (middle), and High (right) Levels of Porosity

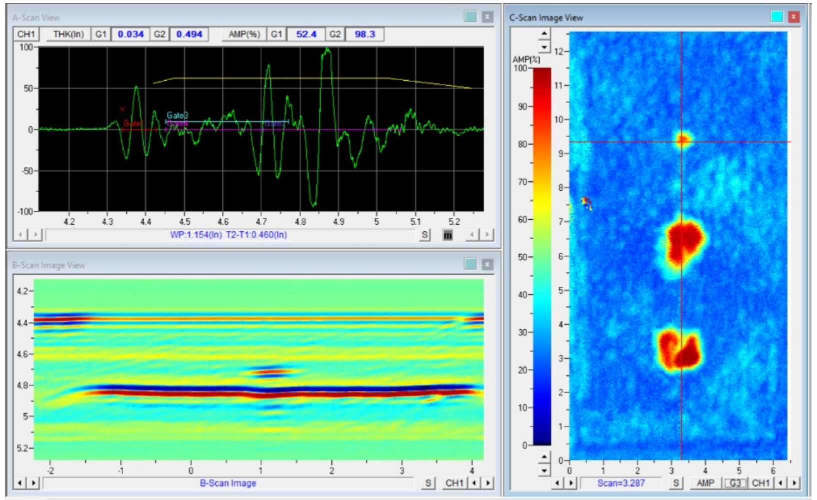
System Development

- Developed first-of-its-kind inspection system that performs defect detection, localization, and quantification during cure in oven and autoclave
- Features:
  - High spatial resolution cure monitoring of resin state and material properties (in addition to defect detection)
  - Scalable from research and development to existing production lines
  - No change required to current part design and limited changes to processing equipment
  - Minor changes to tooling may be required for tool-side inspection of complex geometry



Scanning System Inside Autoclave Prior to Cure

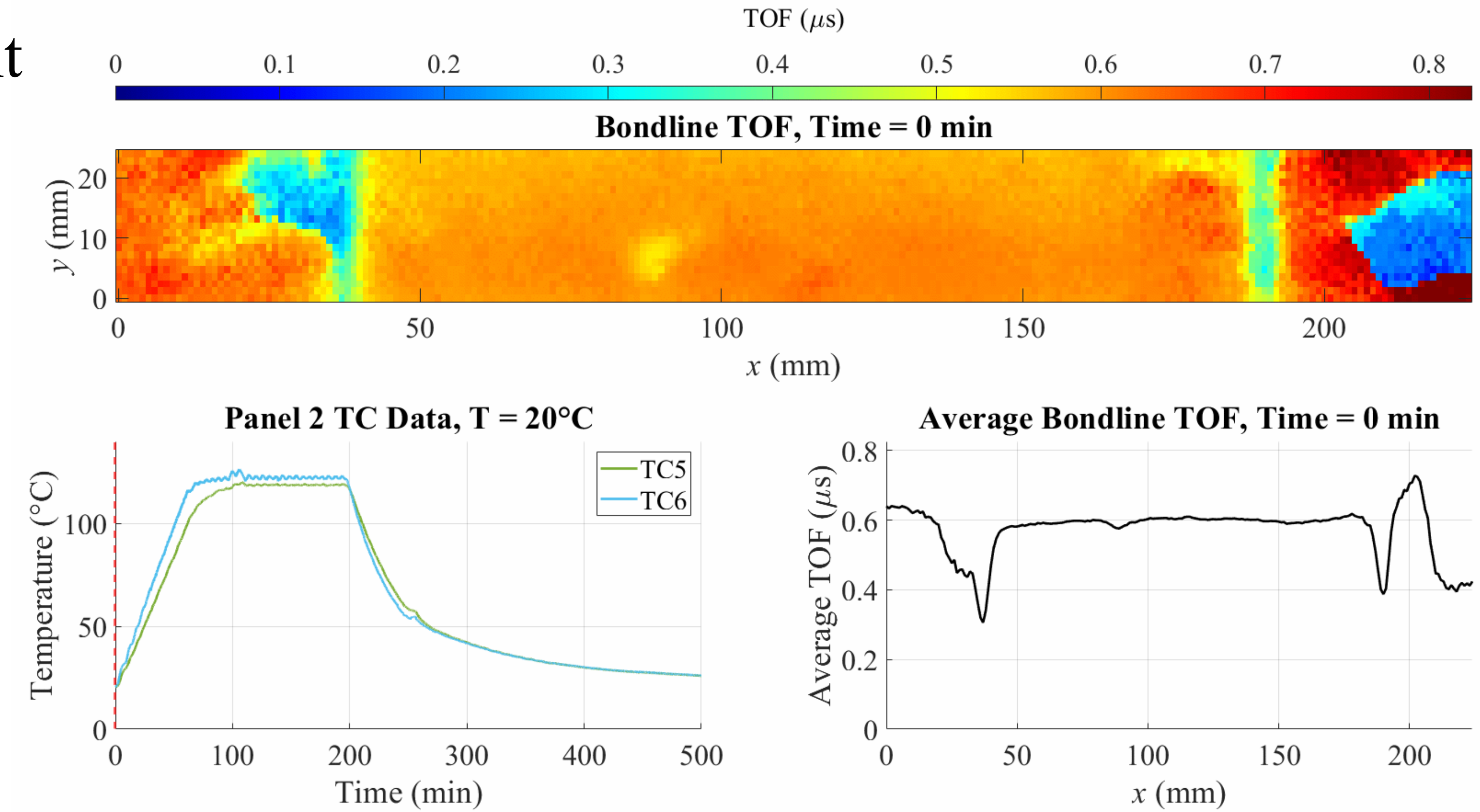




Ultrasonic Measurements (A-scan, B-scan, and C-scan)

Current Work: Bondline thickness measurement during cure

- Bondline time of flight (TOF) measured observable “doming”
- ***Key Result: Scanner enabled real-time monitoring of adhesive flow during cure***



Impact

- Impact:
  - Real-time knowledge of porosity (or other defect) location and quantity during cure
  - Real-time measurement of bondline thickness/adhesive flow and cure
  - Validation of process models and/or processing parameters during certification
  - Control of processing parameters during cure based on real-time measurements
  - ***Results in more efficient process development, shortened certification time, reduction in off-spec parts, and increased production throughput***
- Applications: Aircraft, launch vehicles, satellite buses, automotive, wind turbine blades, marine, etc.
- NASA utilization: Five NASA projects have used the system for materials and process development

Summary

- RAMPT
  - Design and manufacturing technologies to increase scale, significantly reduce cost, and improve performance for regeneratively-cooled thrust chamber assemblies
- AERoBOND/AERoBOND+
  - Enabling reliable and rapid manufacturing and assembly for tomorrow's aircraft
- Cure Process Monitoring of Composites
  - First-of-its-kind inspection system that performs defect detection, localization, and quantification during cure
  - Control of processing parameters during cure based on real-time measurements

Questions?