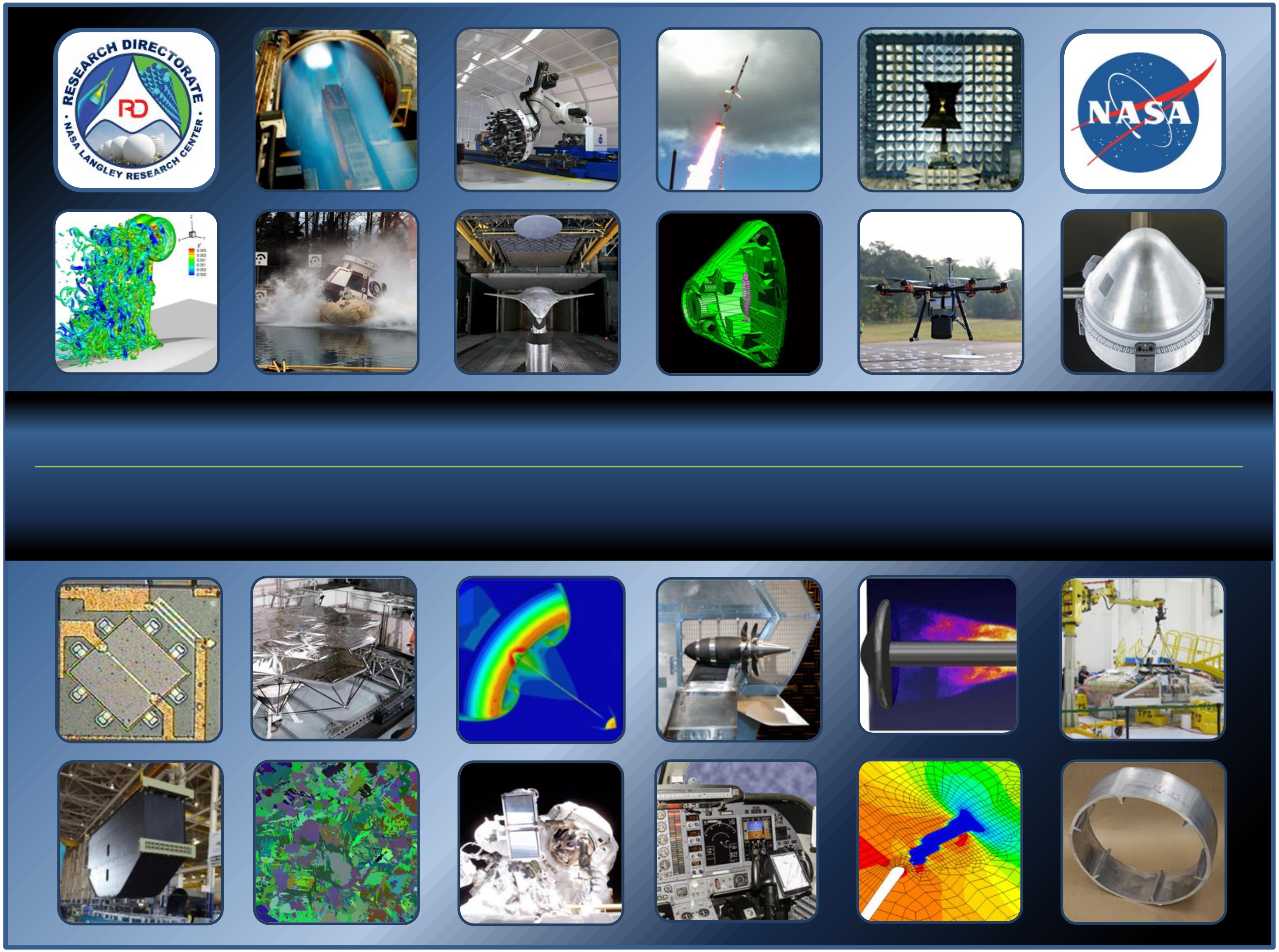
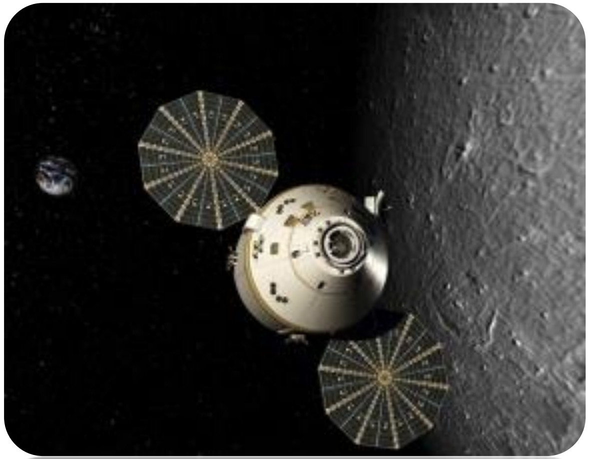
Advanced Materials and Processing Research Directorate



NASA Langley Advanced Materials and Processing Branch: Overview

Dr. Catharine C. Fay – Branch Head
Dr. Terryl A. Wallace – Acting Branch Head

Advanced Materials & Processing
NASA Langley Research Center, Hampton, VA 23681



NASA Langley Research Center

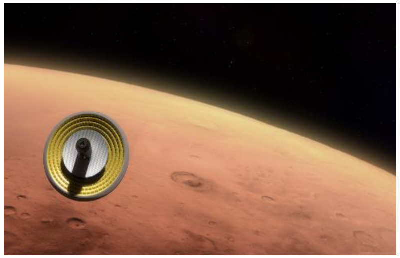
NASA Langley Research Center Hampton, Virginia
Founded in 1917 (NACA): first civil aeronautical research laboratory converted to NASA in 1958
Facilities: $4 billion replacement value
People: 2000 Civil Servants ; 1700 Contractors

All images credit: NASA

The Langley Mission

AERONAUTICS

EARTH SCIENCE



SPACE EXPLORATION

TRANSFORMATION

Image courtesy of NASA

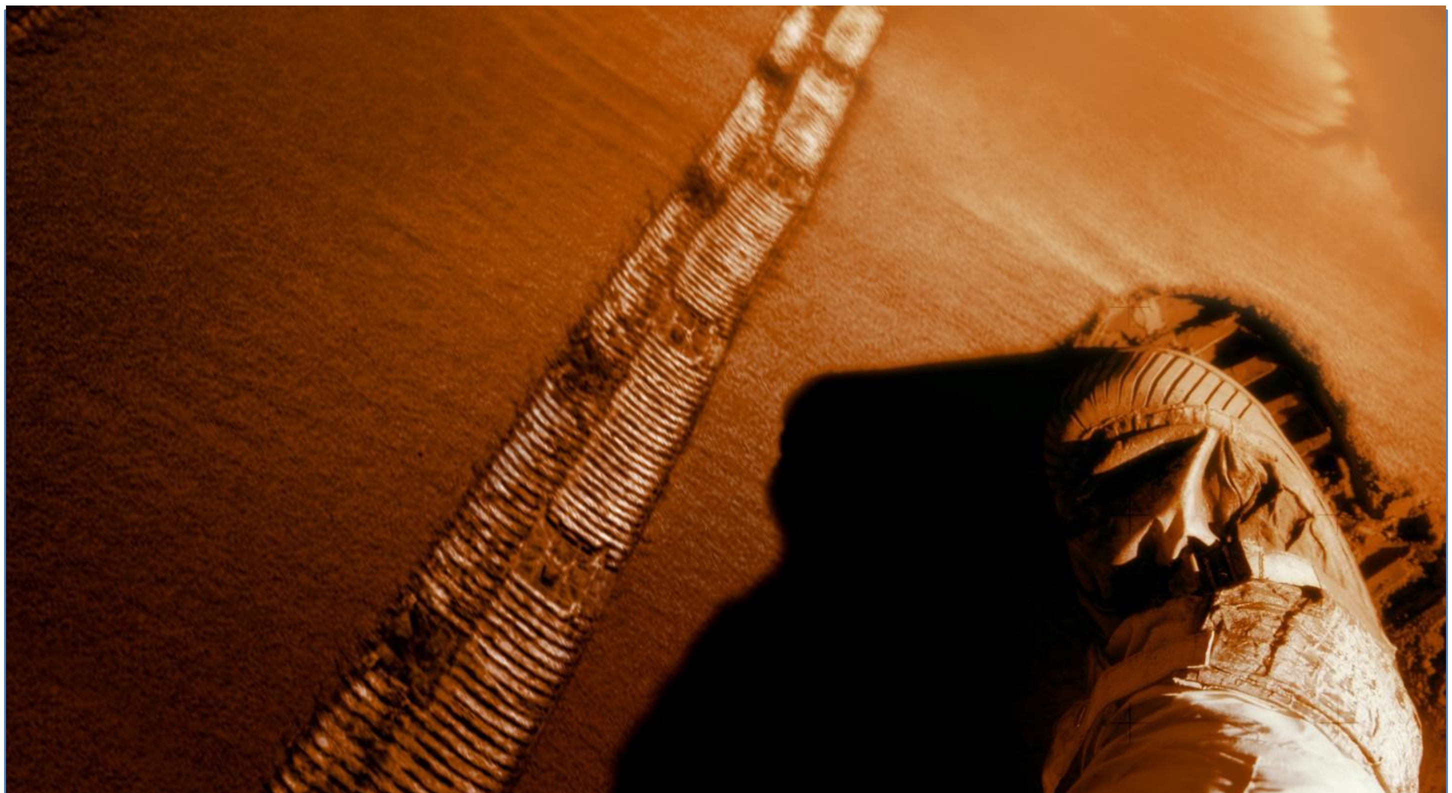
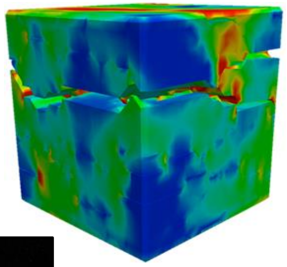
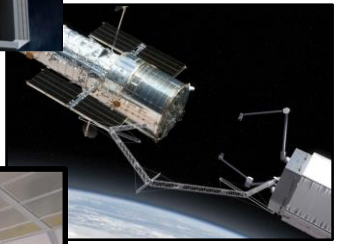


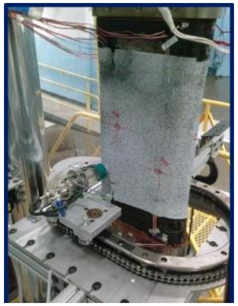
Image courtesy of NASA

Advanced Materials and Structural Systems

Mission Statement : *“We innovate new materials and structural concepts that enable future aviation & space exploration, and develop the foundational technologies essential for manufacturing, design, validation & sustainment."*







Technology Areas

- **Materials**
- **Structures**
- **Mechanisms/Manipulators**
- **Advanced Manufacturing Technology**
- **Flight Qualified Structures**
- **Advanced NDE and SHM Technology**

Advanced Materials and Processing

Workforce: 41 NASA CS, 23 Contractors

Tech Areas

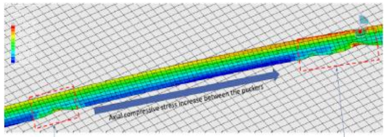
- New Materials Through Synthesis
- New Materials Through Processing
- Composite Processing Technology
- Composite Processing Modeling
- Composite Bonding Technology
- Characterization of Materials
- Computational Modeling and Simulation
- In-space testing of materials

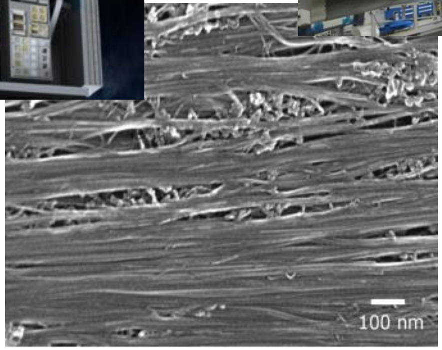
Strategic Objectives

- Increase performance and functionality of load bearing structures
- Improve the efficiency of solid state devices
- Expand the range of operational environments of component technology
- Develop and demonstrate advanced fabrication technology
- Develop validated computational models and simulations to guide materials design

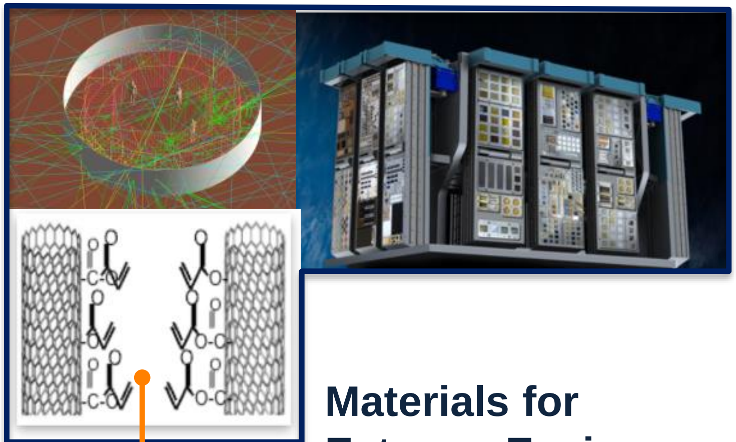
Capabilities

- Synthesis and Modification-Metals, ceramics, polymers, nanotechnology, coatings
- Materials characterization (mechanical, thermal, electrical, spectroscopy, microscopy, extreme environments….)
- Processing (EBF3, 3D printing, Advanced Fiber Placement, composites, ceramics, laser treatment, adhesive bonding, plasma spray, sputtering)
- Modeling and simulation



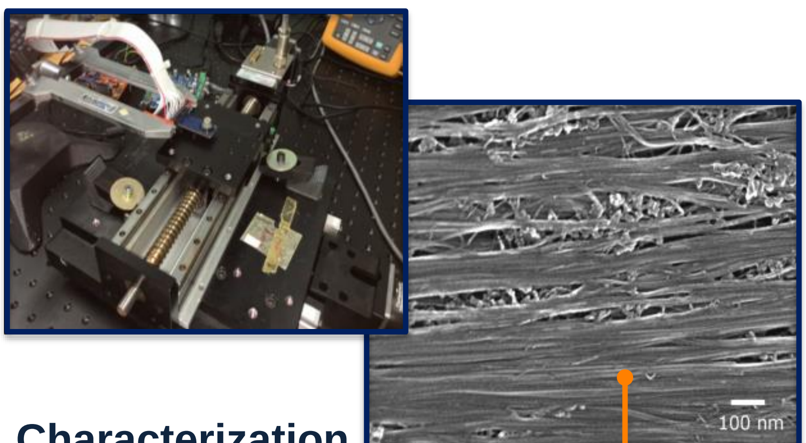


Advanced Materials and Processing Branch (AMPB)

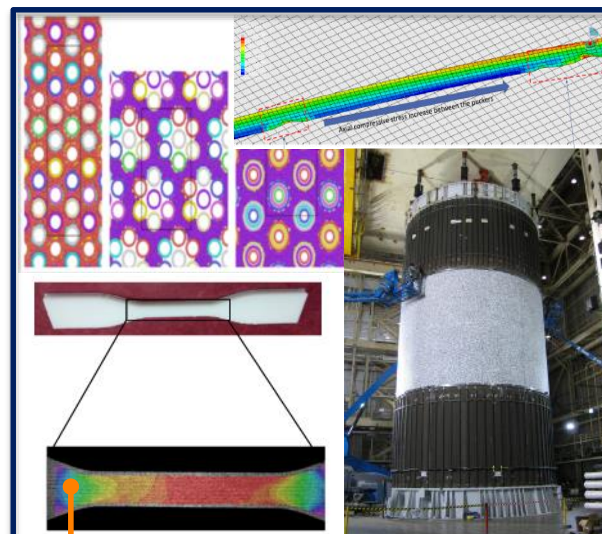


Materials for Extreme Environments

Process Development



Characterization



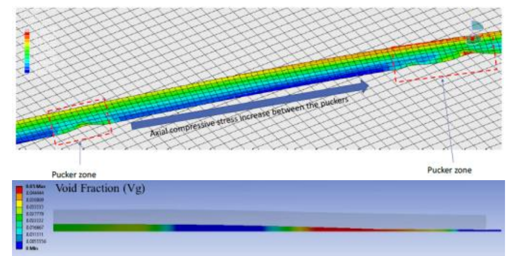
Modeling and Simulation

Advanced Composites

AMPB has capabilities in each step of the composite fabrication process from resin synthesis to inspection

Resin Synthesis

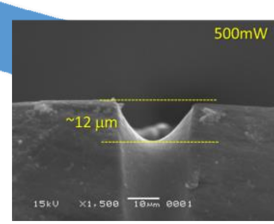
Prepregger



Process Modeling (AFP and Curing)

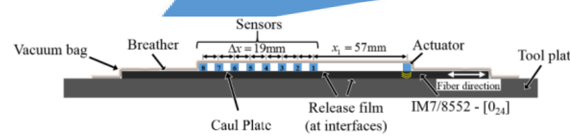
Automated Fiber Placement (AFP)

Curing (Autoclave, ovens, thermal presses)



Laser Surface Preparation and Bonding

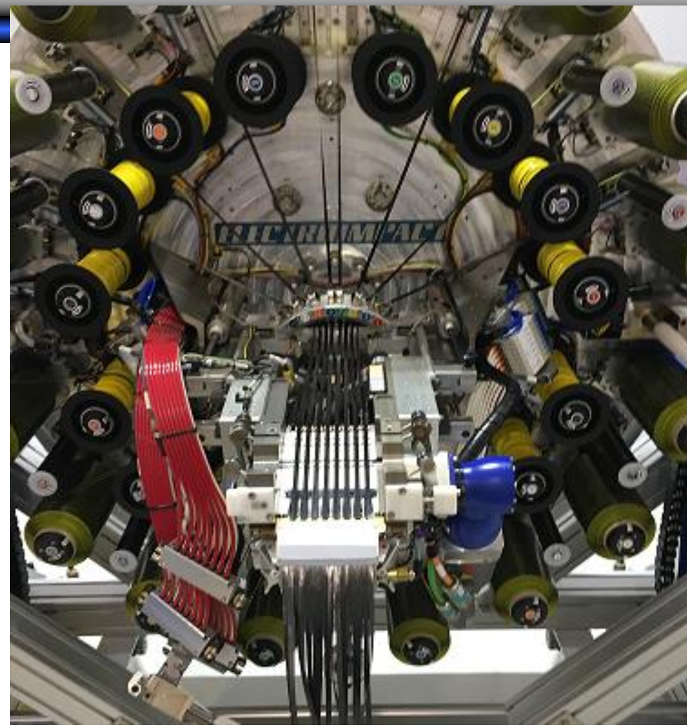
Ultrasonic Inspection

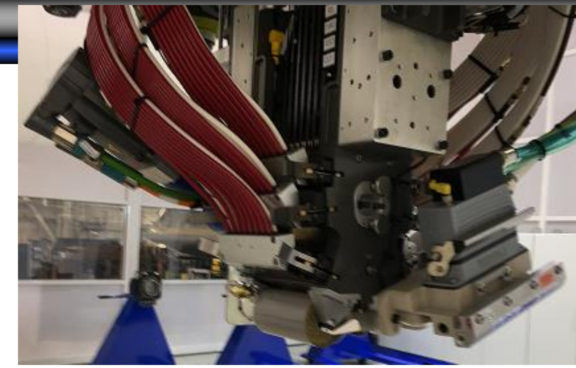


In-situ Cure Monitoring and Inspection

NASA Langley Electro-Impact® AFP Head


NASA LaRC AFP Equipment


AFP STT Guidance and Tensioning System


AFP Compaction roller


AFP Material IR Heater

- **Provides 6-DOF robotic placement of up to 16 tows within customer defined tolerances at rates up to 2000 IPM over ramped, complex surfaces.**
- **Tow tension, material temperature, and compaction load during placement of 0.25" slit-tape-towpreg (STT) on complex-contour tooling have been investigated by NASA and BR&T in a 32-line DoE.**

Advanced Composites Project: AFP Defects Process Model Development

Problem:
Inability to predict and quantify the effects of random and shape induced in-process defects during automated fiber placement (AFP) on complex contour resulting in expensive rework or performance degradation of final component.

Objective:
Develop a physics-based AFP process model based on a deep understanding of the AFP process and the effects of AFP defects on laminate quality and performance.

Approach:
- Rank the common AFP process induced laminate defects(laps, gaps, and wrinkles) by Fabricating flat CFRP panels containing defects and obtain ASTM coupon data to determine the knock-down in mechanical performance.
- Conduct AFP process characterization experiments to develop the depth of understanding necessary to simulate the AFP processing parameters leading to defects which significantly effect laminate performance.

Results:
- Three flat quasi –isotropic IM7/8552-1 panels were fabricated at LaRC utilizing the recently installed AFP equipment (Figure 1) to place 0.25" wide IM7/8552-1 slit-tape in courses containing six tows.
- Two 59" x 27", $[+45/90/-45/0]_{3S}$ panels containing intentional tow gaps in the ply #9 (+45) and ply #11 (-45). Two Gap widths are being investigated based on input from the Boeing Co., including 0.05" and 0.10" (Figure 2).
- One 44"x25", $[+45/90/-45/0]_{3S}$ pristine(no intentional defects was fabricated utilizing identical materials batch and AFP processing parameters to obtain ASTM test coupons for the purpose of laminate strength comparisons in notched and un-notched tension, compression and in-plane shear.

Figure 1. NASA LaRC AFP equipment during fabrication of ACP defect panels

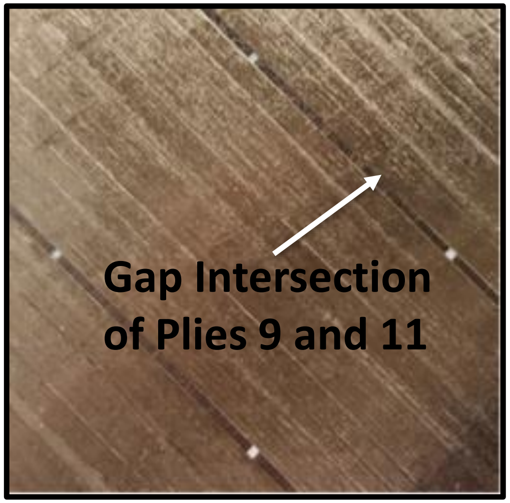


Figure 2. Max gap trial lay-up of plies 9 &11 containing 0.10" gap between 6 tow courses

Automated Surface Treatment and Analysis System for Adhesive Bonding of Primary Airframe Structure

Objective

- **Develop a highly-sensitive, automated, in-line tool to surface treat aerospace structural composites and metal alloys and non destructively inspect the surface prior to adhesive bonding**
  - **Certification of bonded airframe structure with high manufacturing throughput**

Approach

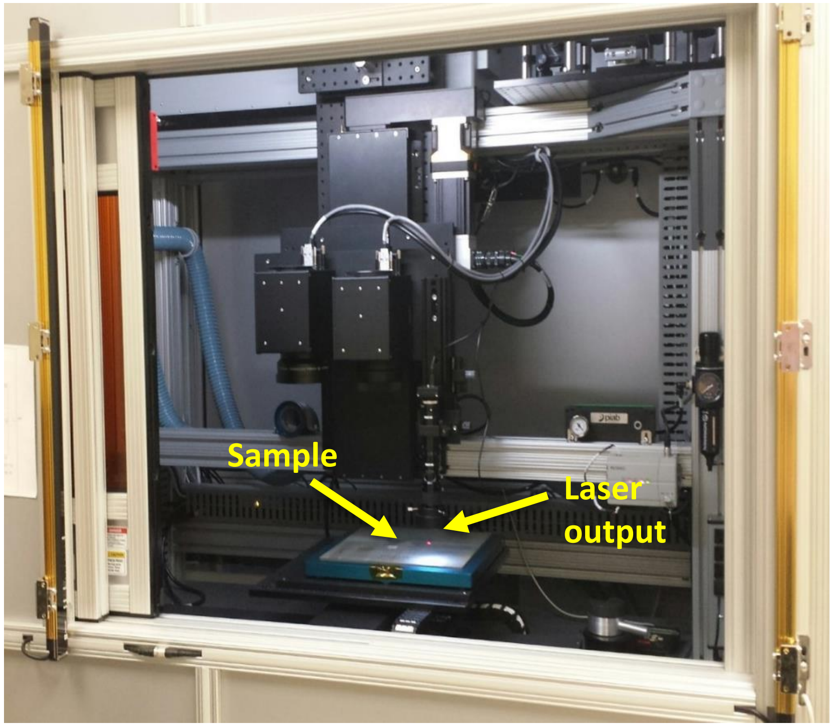
- Follow FAA Guidelines to improve process control for surface treatment and analysis
  - Automated laser surface treatment
  - In-line Laser Induced Breakdown Spectroscopy (LIBS) to measure contamination levels

Benefits

- Increase manufacturing rate by reducing process complexity
- Minimize or eliminate redundant hole-machining and fastener-installation in bonded joints
- Applicable to all aircraft types (large transports to urban air vehicles, metals and composites)
- Enable new manufacturing processes, and aircraft designs with improved flight efficiency

Automated Laser Surface Treatment

- **Ablation with minimal heat effect**
  - **~10 ps pulse duration**
  - **355 nm wavelength (composites)**
  - **1064 nm wavelength (metal alloys)**
- **Sample stationary, laser scan rate up to 127 cm/s**
- **Successfully demonstrated process with carbon fiber/epoxy and thermoplastic composites, and metal alloys including Ti, Al, stainless steel and Inconel**
- **Process validated in collaboration with multiple aerospace prime manufacturers**
- **NASA patented process**



Picosecond Laser System

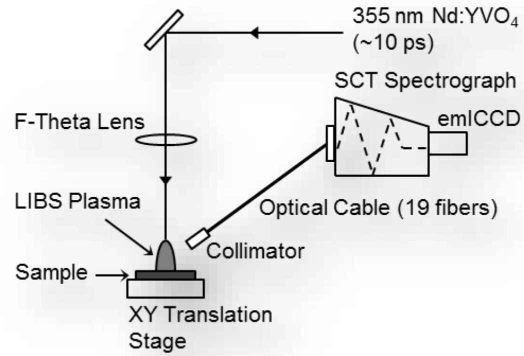
Laser Induced Breakdown Spectroscopy (LIBS)

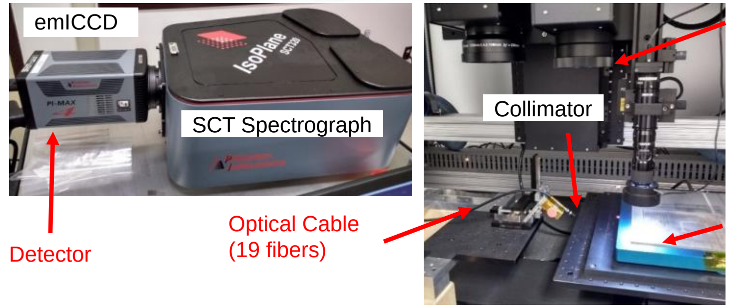
How it works

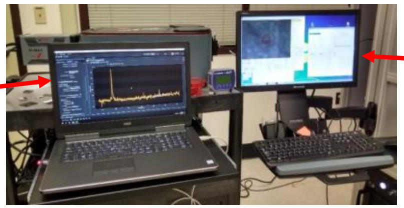
- Picosecond laser ablates substrate forming a plasma plume
- Plasma emissions measured by spectrometer/detector
- Ratio of Si to C peak height *quantifies* silicone contamination level

Benefits

- Real-time detection of minute quantities of most detrimental contaminants (Silicones)
- No sample preparation or special atmospheric conditions needed
- Can create a map of the surface contamination distribution
- Nearly non-destructive
- Automatable
- Can be integrated with the laser surface treatment process for closed-loop control of pre-bond surface preparation to ensure acceptable surface cleanliness
- Potential to realize process yield needed for certification of adhesively bonded primary airframe structure







Cryogenic Tank Manufacturing
- Problem and Solution -

Problem
- Machined/welded construction of launch vehicle cryotanks is expensive, heavy, and risky

Integrally Machined
- 90% Scrap Rate
- Approx. 540,000 lbs. Chips/Tank
- $8M Chips/Tank

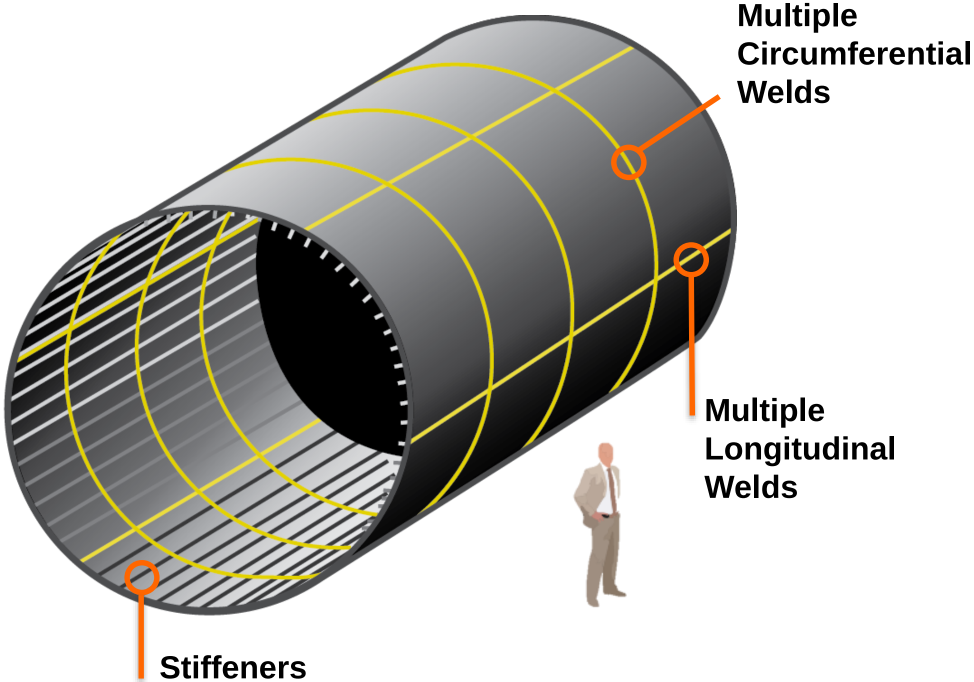
Welded Structure
- Material Property Knockdown; Defects
- Approx. 0.5 Miles of Welds

Solution
- Use Advanced Near Net Shape Technology (ANNST) to manufacture cryotanks which are cheaper, lighter, with fewer welds
- Single-piece stiffened barrel in one processing step via **Integrally Stiffened Cylinder (ISC) process**

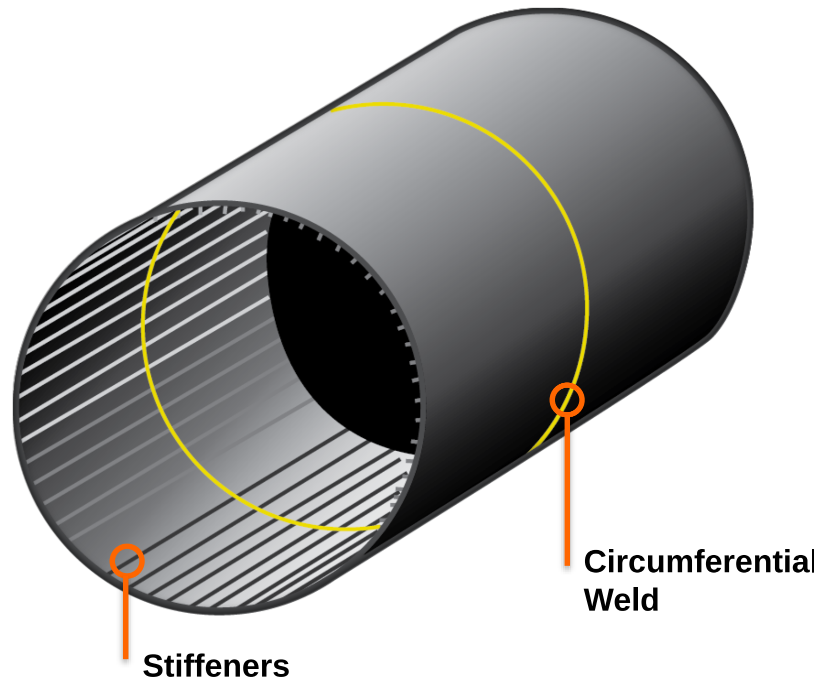
- Capital investment to establish U.S. ISC capability ~$8M
  - **$8M = scrap Al from one Shuttle External Tank**

Comparison of Manufacturing Technologies
- 16-ft. diameter x 40-ft. long barrel -

Conventional Fabrication
Multi-piece, welded construction



Integrally Stiffened Cylinder (ISC) Process
Near-net shape construction



Advantages of ISC Process

- Minimizes machining
- Eliminates longitudinal welds
- Reduces number of circumferential welds

Estimated Benefits

- 50% cost reduction[1]
- 40% schedule reduction[1]
- 25% increase in buckling load[2]
- 10% mass reduction[1,2]

[1]*Stoner, et al. "Cost-Benefit Analysis for the Advanced Near Net Shape Technology (ANNST) Method for Fabricating Stiffened Cylinders." NASA/TM-2016-219192.*
[2]*Rudd, et al. Buckling Response of a Large-Scale, Seamless, Orthogrid-Stiffened Metallic Cylinder." AIAA SciTech Forum, 2018.*

ISC Technology Maturation

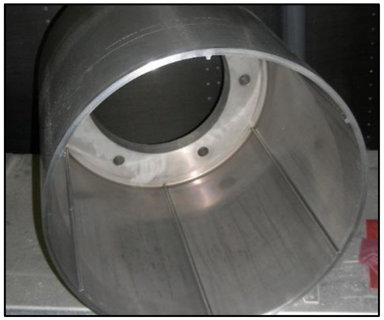
FY11-12
Proof of Concept with Al-Li Alloy

- 0.2 in. tall stiffeners
- 8 in. diameter

FY12-13
Increased Stiffener Spacing and Height

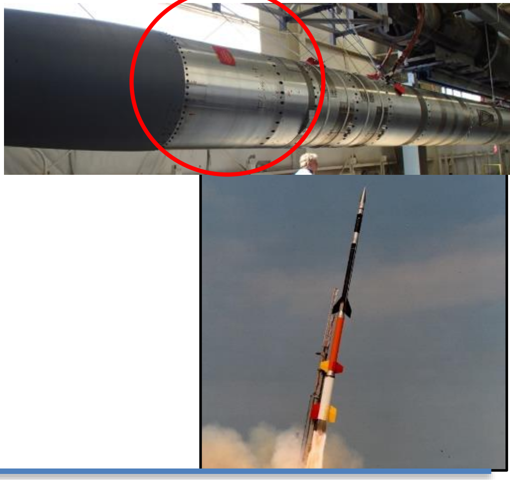
- Multiple stiffener shapes
- 0.75 in. tall stiffeners
- 8 inch diameter

FY15
6061 Aluminum Sounding Rocket ISC

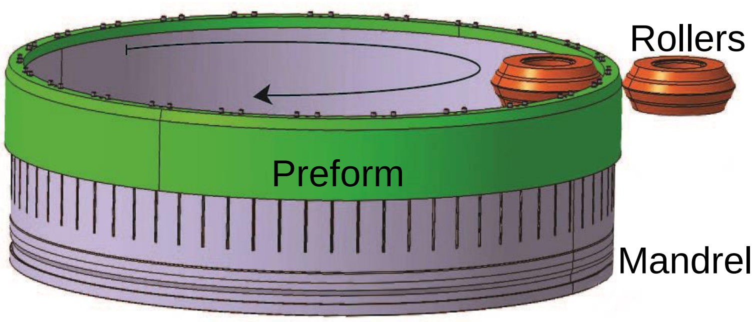


- 17 in. diameter
- 20 in. length

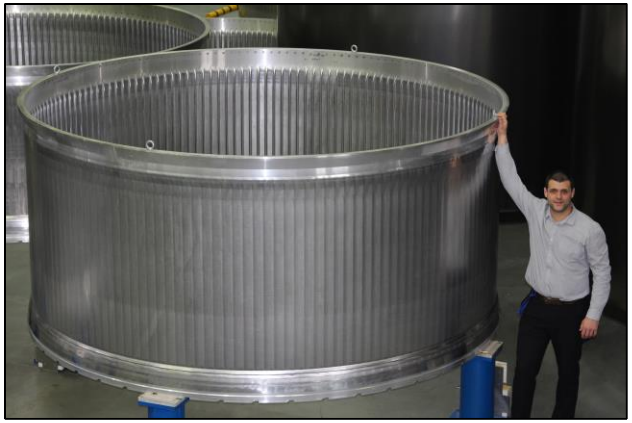
Success Flight Demonstration
Oct. 7, 2015



FY17-19 Demonstration at Commercial Launch Vehicle Scale



- Flow forming process using counter rollers and mandrel
- Preform thinned and elongated, while material is forced into grooves to form stiffeners

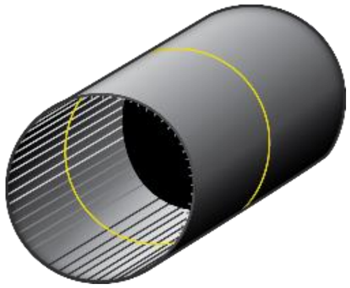


Multiple 10-ft. diameter ISCs fabricated

Proposed Metallic Fuselage Manufacturing Demonstration

<u>Proposed Effort under Advanced Air Transport Technology (AATT):</u>

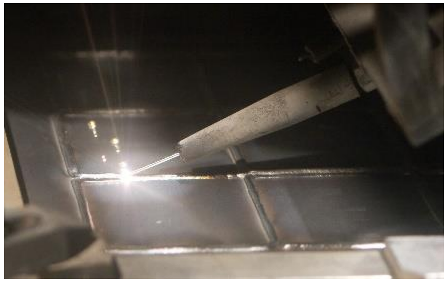
- Select advanced Al alloy with formability and additive manufacturability, high combined strength and toughness
- Fabricate single-piece Integrally Stiffened Cylinders (~10 ft. dia. x 10 ft. long) with longitudinal stiffeners
- Demonstrate joining technology for assembly of two cylinders into 20-ft. long fuselage structure
- Optimize structural design incorporating tailored, selective reinforcement for durability and damage tolerance
- Build-up window, door and circumferential ring frames with large-scale additive manufacturing
- Structural test to validate manufacturing demonstration, structural models and analysis



Integrally Stiffened Cylinder

- *Significantly reduces production time and cost*
- *Reduced weight through eliminating fasteners*

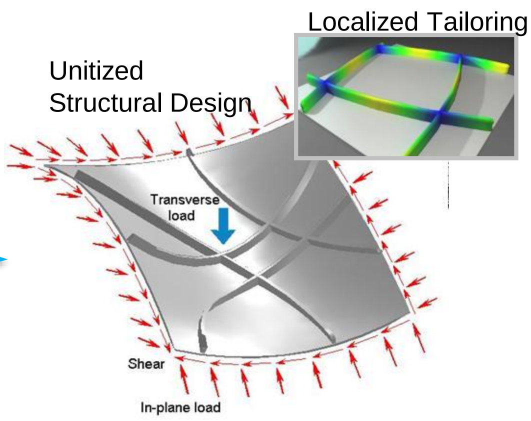
+



Directed Energy Deposition

Structural Reinforcement through Additive Manufacturing

- *Automates assembly, enables local reinforcement*
- *Improves performance and damage tolerance (design life)*



Tailored Structural Design

- *Reduces weight, time, cost*
- *Exploits advanced manufacturing capabilities*

VUD 600 Multi-Purpose Rapid / Advanced Manufacturing R&D Machine

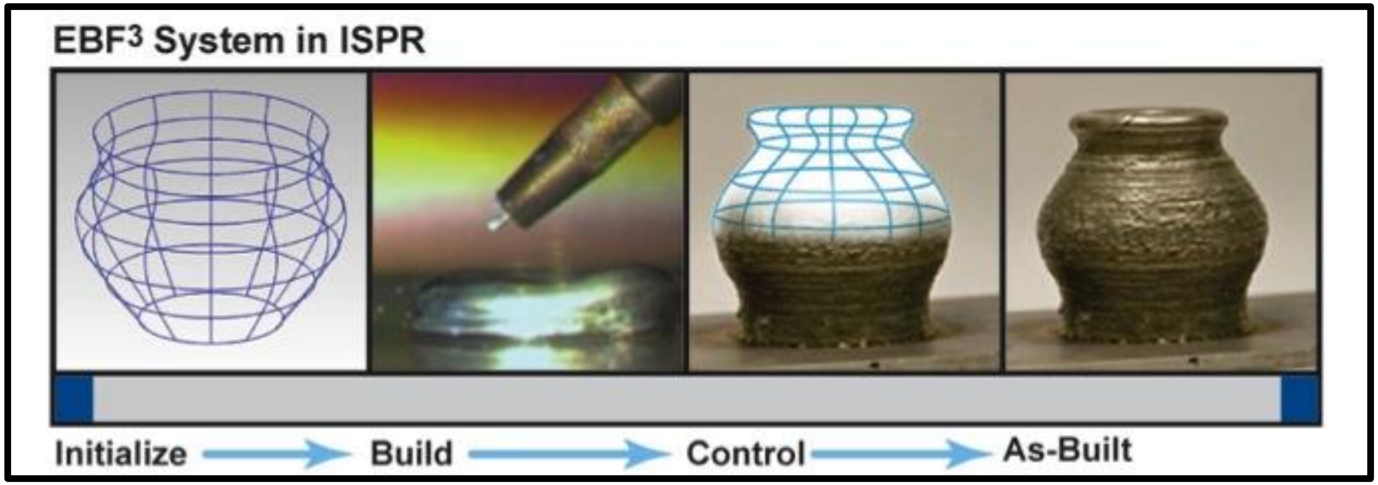
Capabilities:

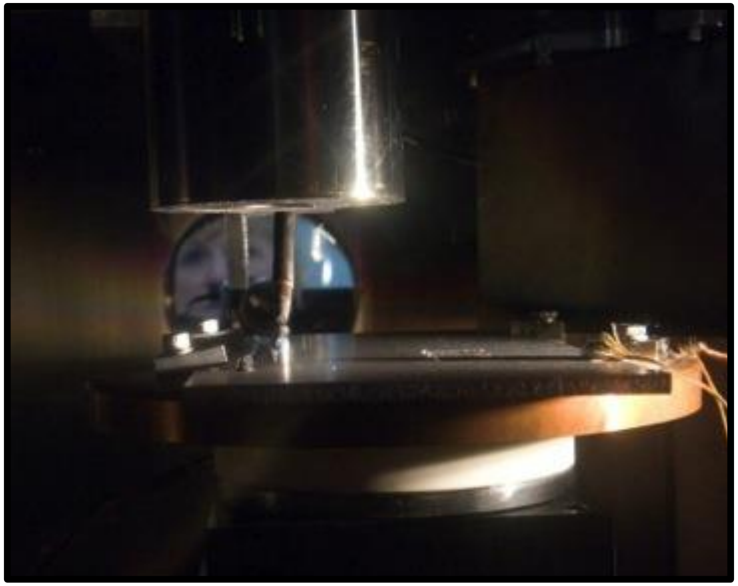
- Metals and thermoplastics
- Forward & back flow forming
  - Integrally Stiffened Cylinder (ISC)
- Counter rolling (nosecones, bulkheads)
- Spin forming (domes, bulkheads)
- Conical forming (nosecones, frustum)
- Cold and warm forming (up to 930° F)
- Profiling and tapering
- Functionally-graded structures
- Forming w/ and w/out mandrel

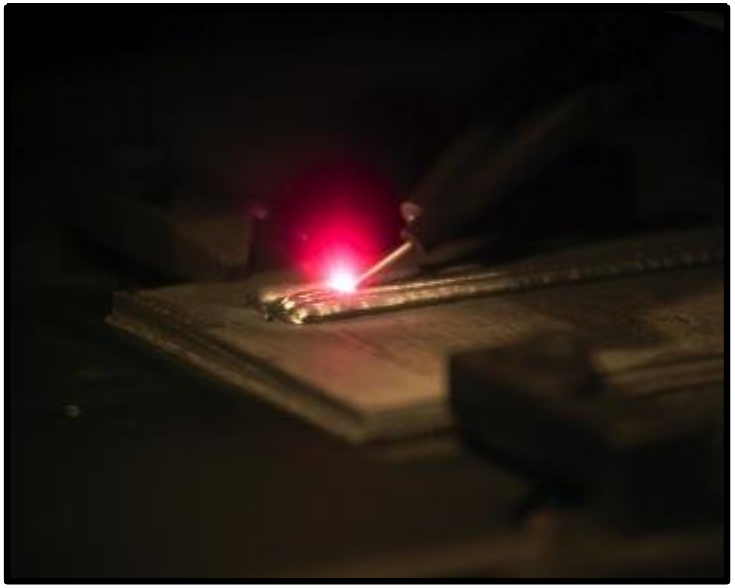
VUD 600 Machine Video:

https://www.youtube.com/watch?v=TQw0lZ-qmtM

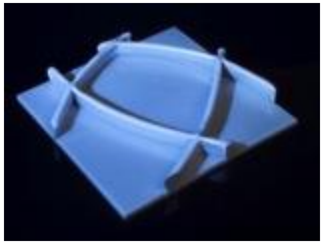
EBF³ Build Process





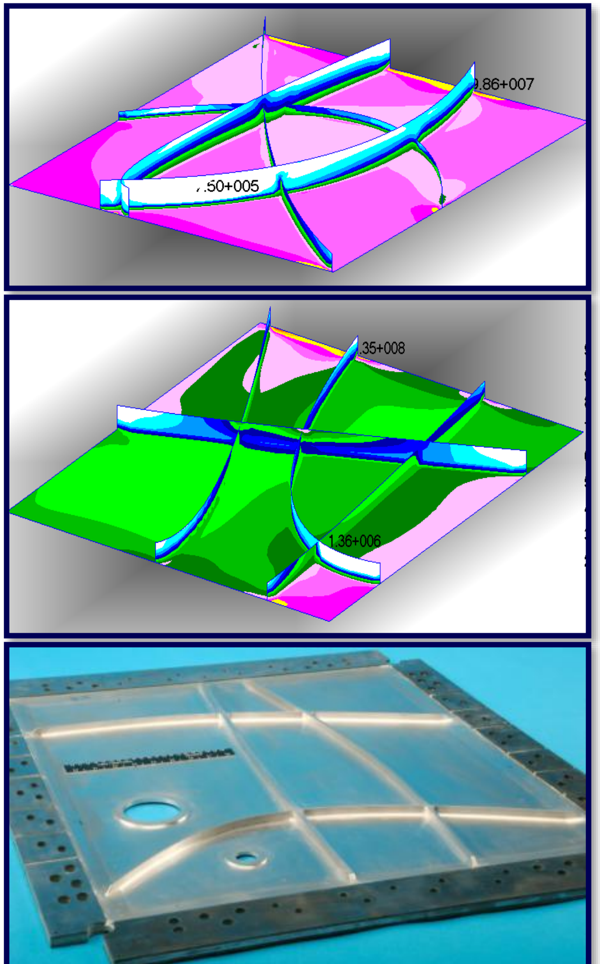


Structurally optimized panel



Microgravity testing

Optimized Structural Design



Structurally optimized panel designs & machined test panel

Funder

NASA Aeronautics – Fixed Wing & Supersonics Projects

Challenge

Optimize aircraft structural efficiency through structural design and analysis tools (development at VA Tech funded by NASA)

Current Work

- **Design and optimization tool development:**
  - **Contoured stiffeners that follow load paths**
  - **Acoustically-tailored fuselage structures**
  - **Aeroelastically-tailored wing structures**
  - **Functionally graded stiffeners for material properties tailored to structural needs**
  - **Selectively reinforced structures for improved stiffness and damage tolerance**
- **Build and test panels for code validation**

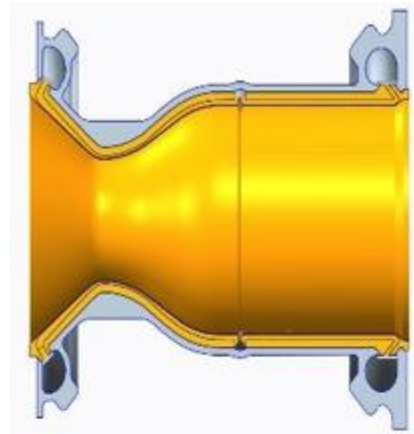
Electron Beam Freeform Fabrication (EBF^3) Functionally Graded Rocket Nozzle

Basics:

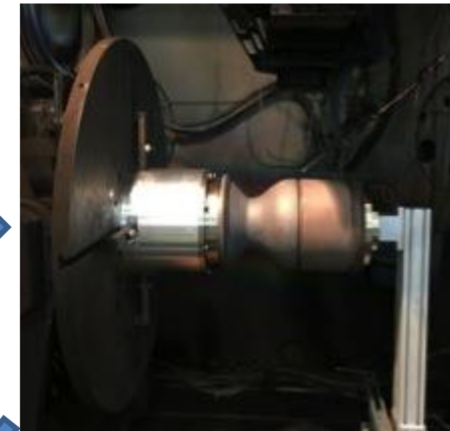
- **Additive manufacturing being investigated for next generation rocket engine components**
- Copper combustion chamber and nozzle produced via Selective Laser Melting (SLM)
- **Functionally graded** from copper to nickel for structural jacket and manifolds enabled using **Electron Beam Freeform Fabrication (EBF^3)**
- Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing

Benefits:

- **Reduce injector manufacture time** from months to weeks
- **Increased performance** through improved cooling with conformal passages enabled by additive manufacturing
- Potential to **reduce full scale injector cost** by nearly an order of magnitude (~90% reduction)

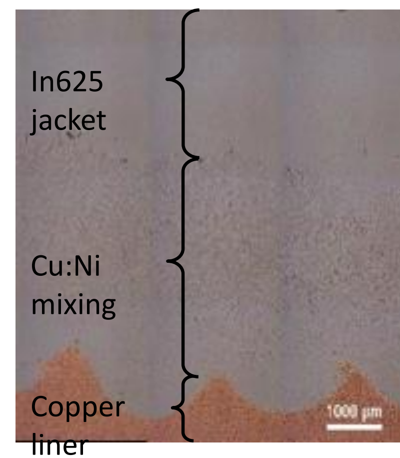


Schematic of Cu-Ni graded rocket nozzle



EB weld SLM Cu liner in LaRC EBF^3 chamber

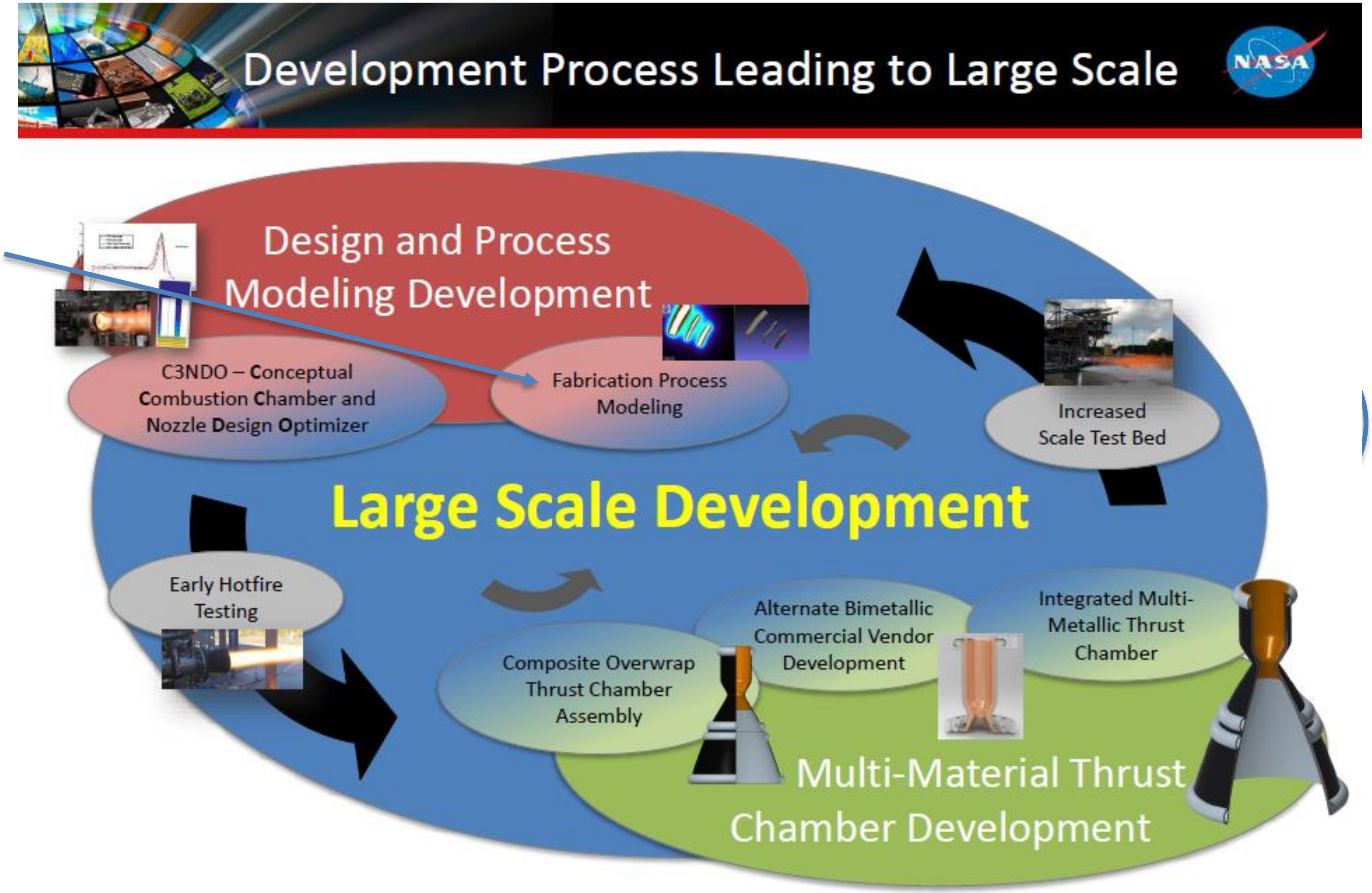
Structural Inconel 625 jacket EBF^3 deposited onto SLM Cu liner



Microstructure of graded interface

Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) Project

Process modeling tools for metallic additive manufacturing to be developed by LaRC and ARC



Iterative process development, subscale testing and test bed hot fire testing to develop technologies feasibility, anchor data and reduce overall project risk

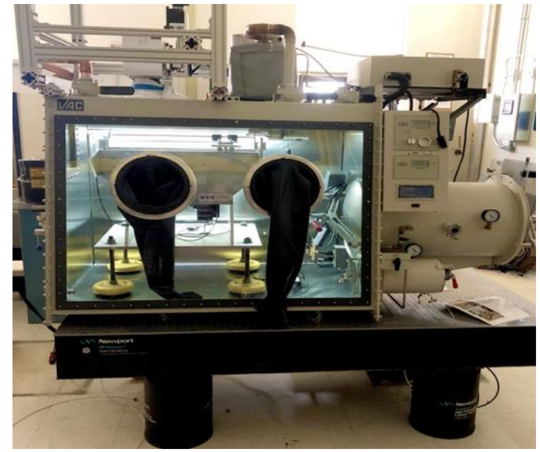
Configurable Architecture Additive Testbed [CAAT] : for R&D of Certification Tools for LPBF

OVERALL OBJECTIVE

Develop a set of *validated* tools for optimization, certification and sustainment of new designs that are enabled by advanced manufacturing methods.

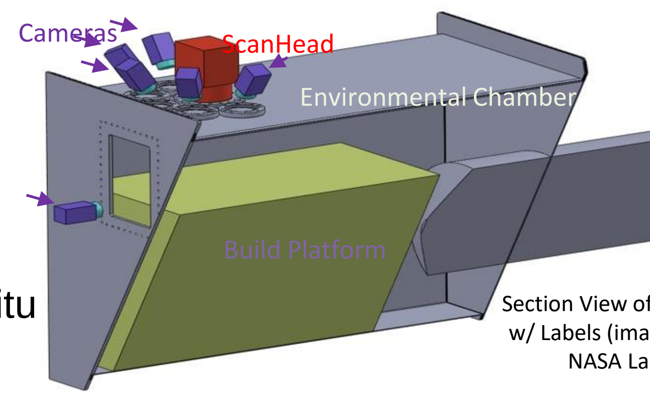

In-Situ Thermal Monitoring


In-Situ, in-plane spatter


Configurable Architecture Additive Testbed [CAAT] (image credit: NASA LaRC)

APPROACH

- Use CAAT as a development platform.
  - Experiments to increase confidence models.
  - In-situ data : Video and Thermal cameras (include laser inline), plume emissivity, in-situ accelerometers, in-situ thermocouples, ppm humidity, ppm O_2 monitoring.
  - Post-build: material & defect characterization.
  - Pursue statistically significant relationships between in-situ monitoring and defects.

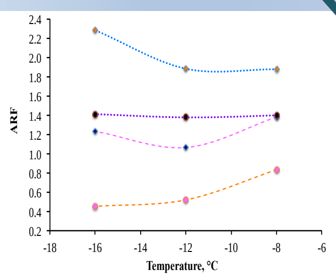


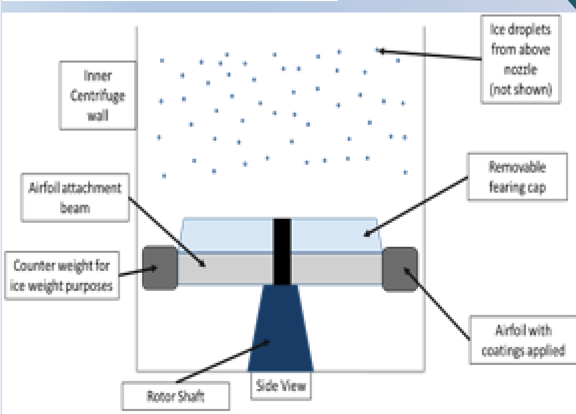
Section View of the CAAT w/ Labels (image credit: NASA LaRC)

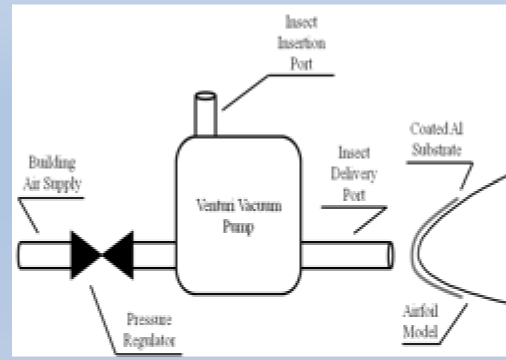
Laboratory for Adhesion Mitigation Projects

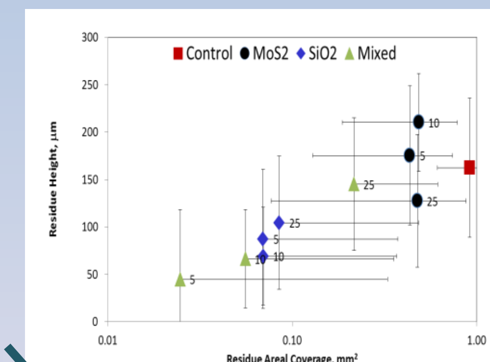
Insect Residue Adhesion Mitigation

Ice Adhesion Mitigation

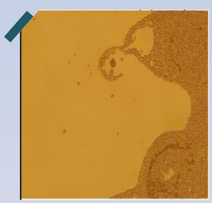


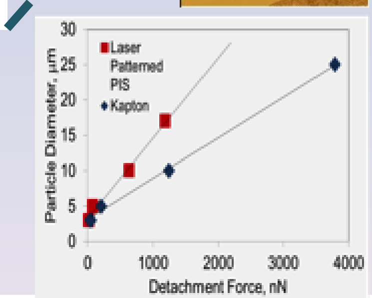


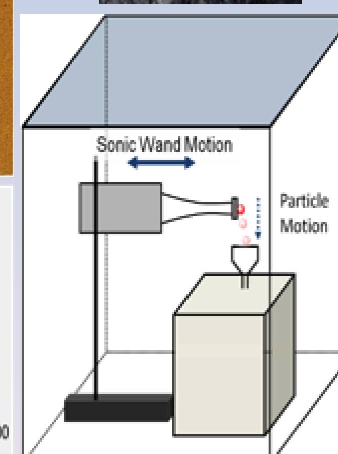




Particulate Adhesion Mitigation



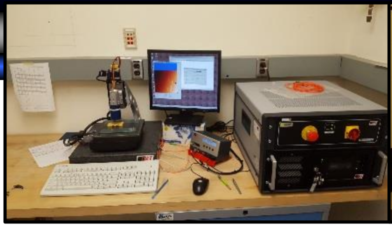




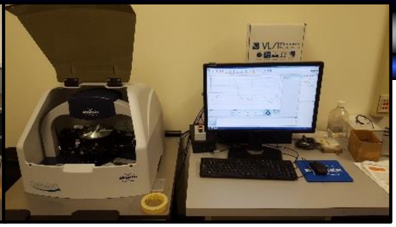
Set-up of Durability Lab/In-house Ice Accretion Capability

Other Coating Characterization Capabilities

Pneumatic Insect Delivery Device



Optical Profilometer



Contact Profilometer

QUV Accelerated Weathering Instrument

(Left-to-Right) Film Thickness Gauge, Handheld Optical Profiloemter, Mandrel Bend Test Device

Temperature/Humidity Chamber

(Left-to-Right) Handheld Roughness Gauge, Pencil Hardness Test Kit, Sclerometer (Hardness) kit

(Left) Barcol Hardness Gauge, (Right) Shore A Hardness Gauge

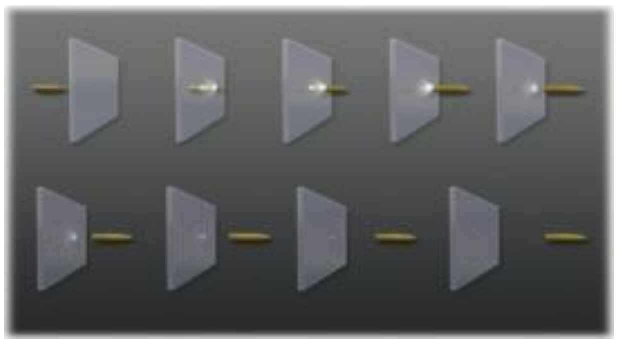
Additional Equipment: Impact Tester, Contact Angle Goniometer, Scribe Tester, Taber Abrasion Wheel, Sand Blast Treatment

POC: Christopher Wohl and Joseph Smith

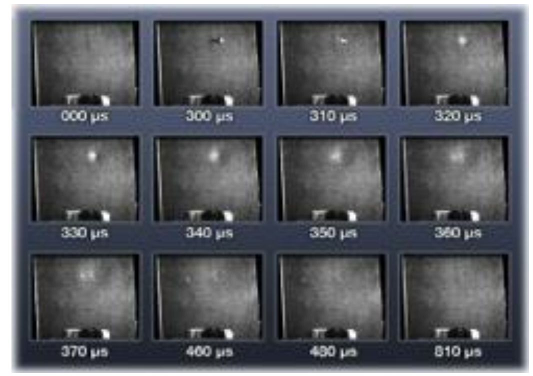
Self-healing Materials

Overview: Self-healing materials development based on inherent healability due to molecular design

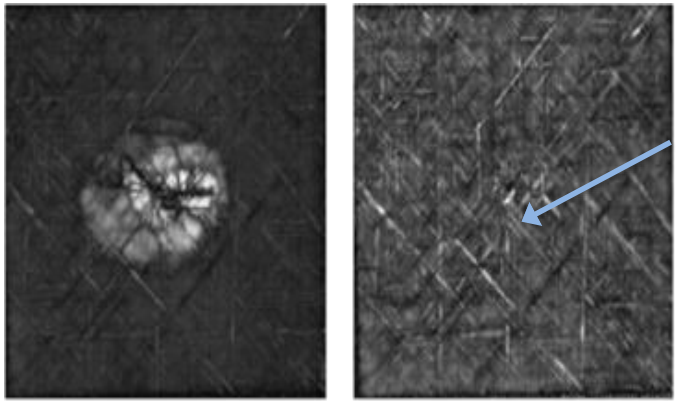
- Healing induced by energy imparted by damage event
- Material design not based on monomer encapsulation



Puncture healing concept



Rate of puncture healing from high velocity projectile penetration

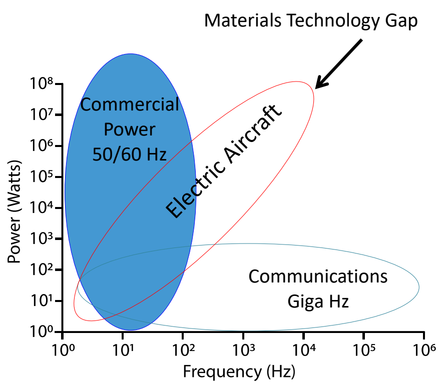


Except for broken fiber, NDE shows no evidence of damage

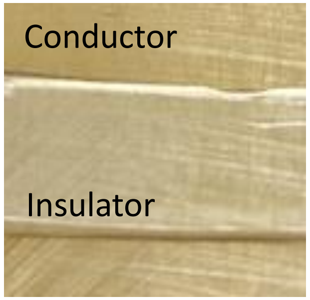
Improved damage tolerance of composites with self-healing matrix

POC: Mia Siochi, emilie.j.siochi@nasa.gov
Keith Gordon, keith.l.Gordon@nasa.gov

Self-Healing Materials for High Voltage High Frequency Insulators

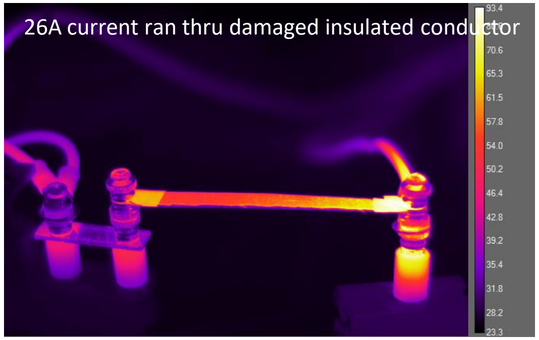


Motivation: Gap in materials to support high voltage high frequency electric propulsion.



Synthesis of insulating materials

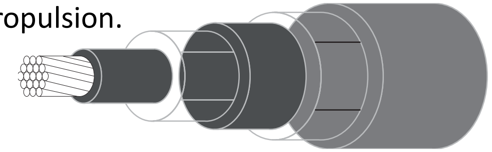
Custom test apparatus to assess real-time scratch healing under simulated use conditions.



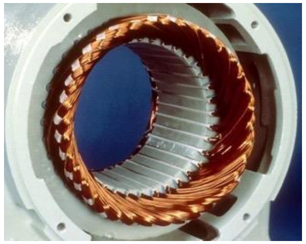
Insulator has been damaged

After heating, the insulator has healed and
the damage is no longer present.

Prototype testing of self-healing insulation



Thick film insulator for integration into multilayer cable system



Wire coatings for electric motors

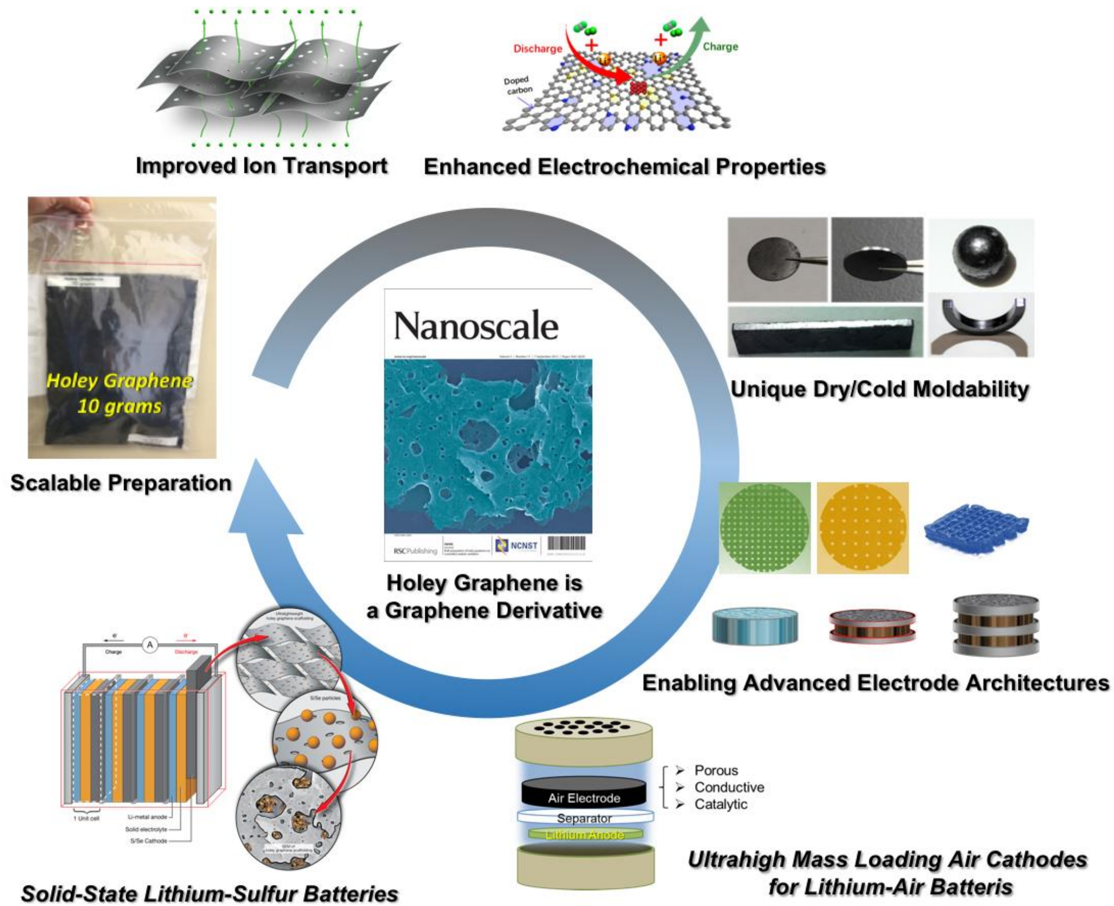
POC: Mia Siochi, emilie.j.siochi@nasa.gov

Holey Graphene Materials for Energy Storage

Holey graphene

- ❑ Is an advanced graphene derivative
- ❑ Has through-thickness holes on graphene sheets
- ❑ Allows improved ion transport paths
- ❑ Is advantageous for electrochemical energy storage applications
- ❑ Is scalable in synthesis and processing
- ❑ Is unique in its dry/cold moldability
- ❑ Enables advanced electrode architecture fabrication

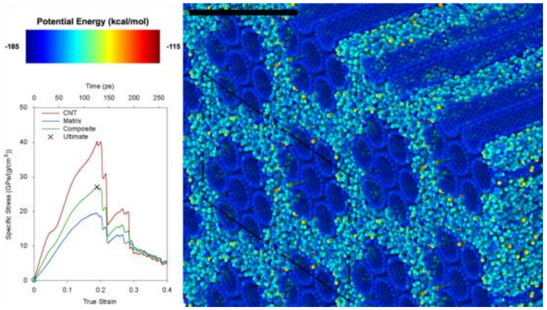
- ○ *2 patents and multiple patent applications*
- ○ *> 20 peer-reviewed journal publications*



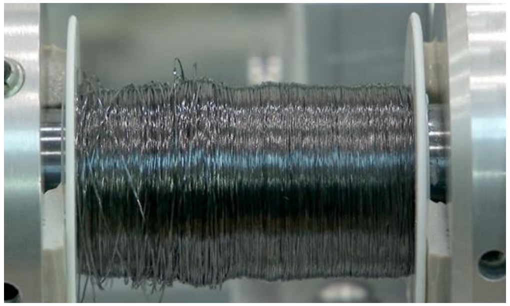
<u>Applicable in various energy storage applications:</u>

- ❑ Supercapacitors
- ❑ Li-ion batteries
- ❑ Li-S batteries
- ❑ Li-air/O_2 batteries
- ❑ Li-CO_2 batteries (for Mars applications)

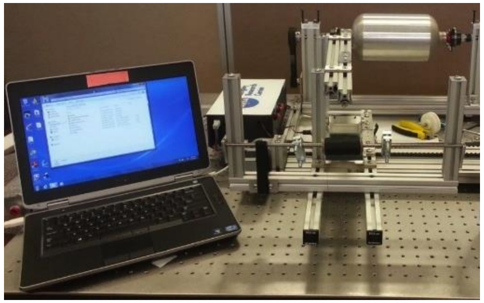
Computationally Guided High Strength Carbon Nanotube Composite Development



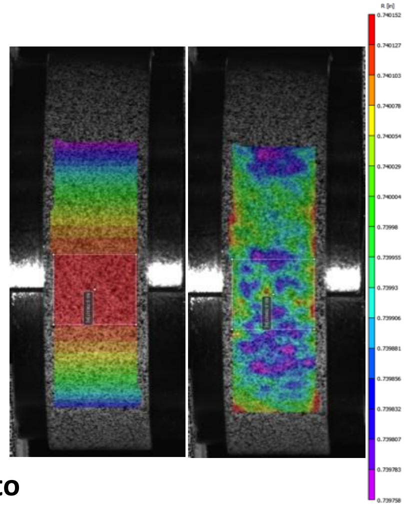
Computational modeling of CNT composite



Collaborate with industry to scale up high strength CNT

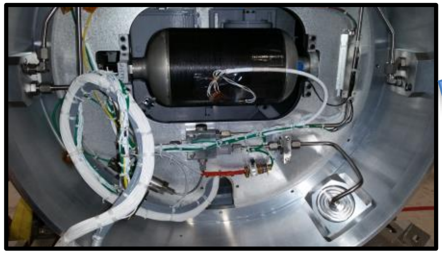


CNT composite process development

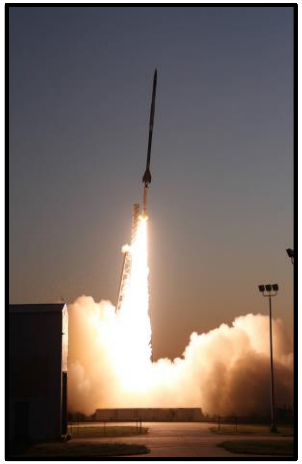


CNT composite test method development

Transfer of CNT processing method to commercial winder at MSFC to manufacture flight test article



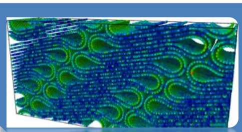
Integrate flight test article



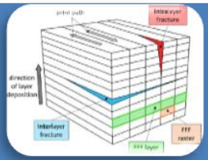
Flight test CNT composite technology

POC: Mia Siochi, emilie.j.siochi@nasa.gov

Printing for Aerospace Applications

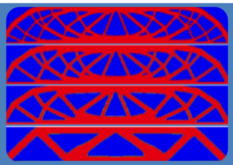


Atomistic Modeling



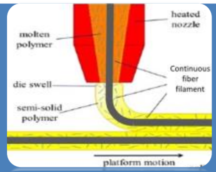
Mechanics of Materials Modeling

Young, et al., Additive Mfg, **22**, 508-515 (2018).



Topological Optimization

Guest, J. K., NASA LaRC 2015.

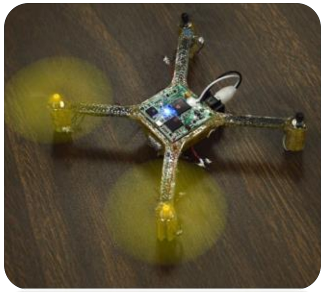


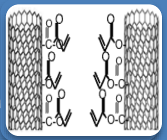
Process Modeling

Baird, D. G., Bortner, M. J. NASA LaRC 2016.

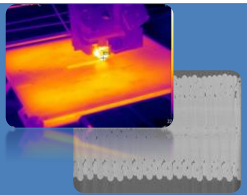
Systems Analysis

Human Mars Design Reference Architecture (5.0) NASA-SP-2009-566.

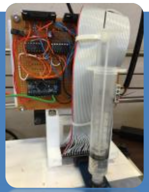




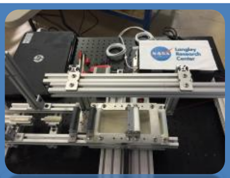
Chemistry



Materials Characterization



Sensor Fab and Characterization

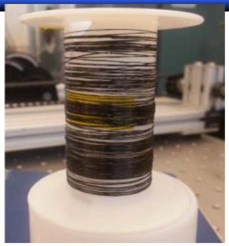


Composite Processing

3d Printing

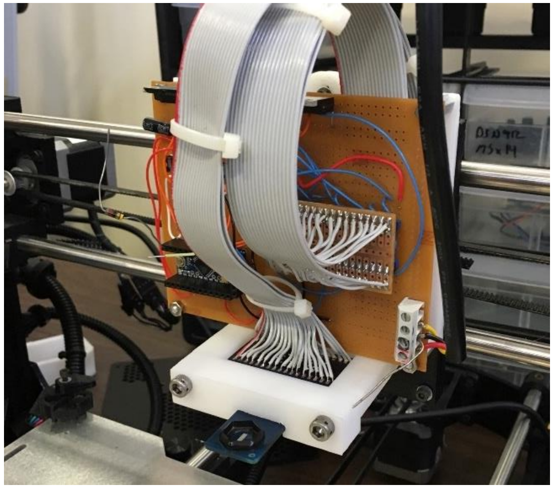
POC: Mia Siochi, emilie.j.siochi@nasa.gov

3D Printing Carbon Nanomaterials in Multifunctional Parts

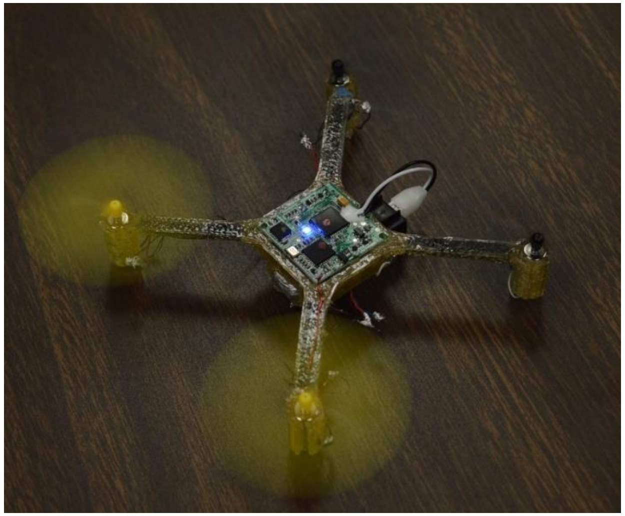


CNT Yarn

Graphene

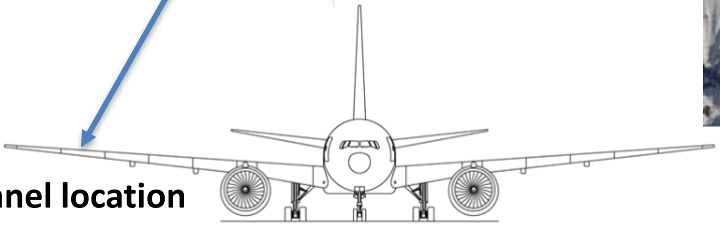


NASA developed 3D printer



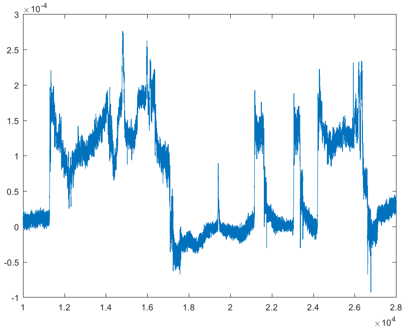
3D printed multifunctional quadcopter

Embedded 3d printed nanosensors on flight article



Panel location

Boeing 2018 EcoDemonstrator

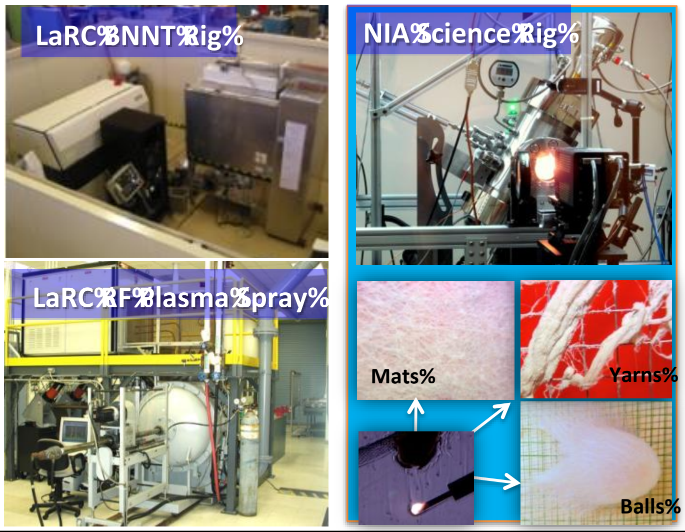


Strain sensor data from flight test

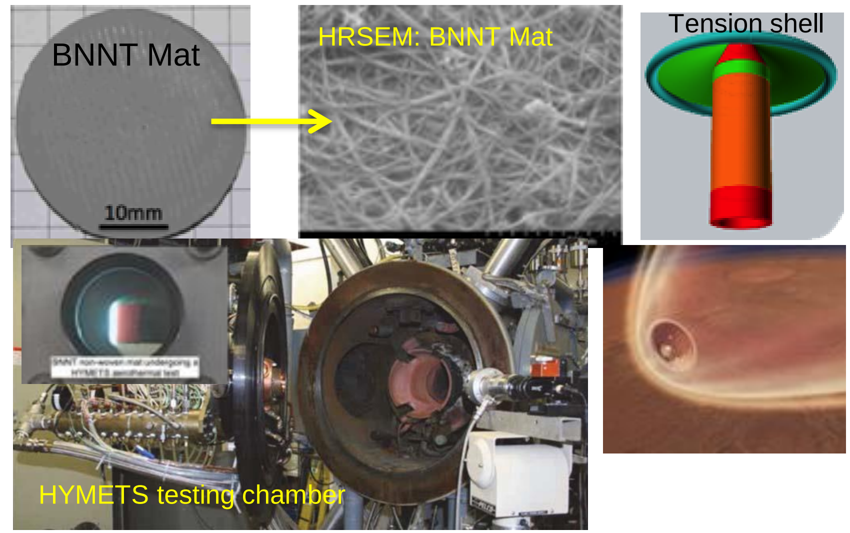
POC: Mia Siochi, emilie.j.siochi@nasa.gov

Boron Nitride Nanotube and BNNT Composites

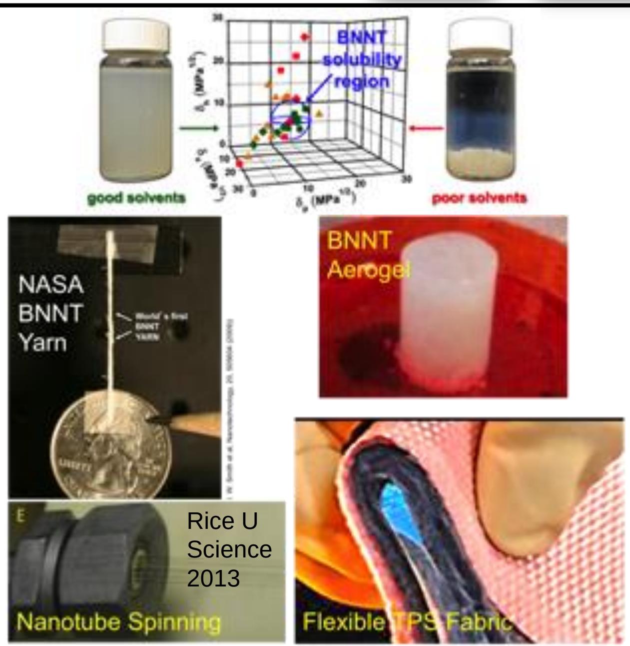
BNNT Synthesis



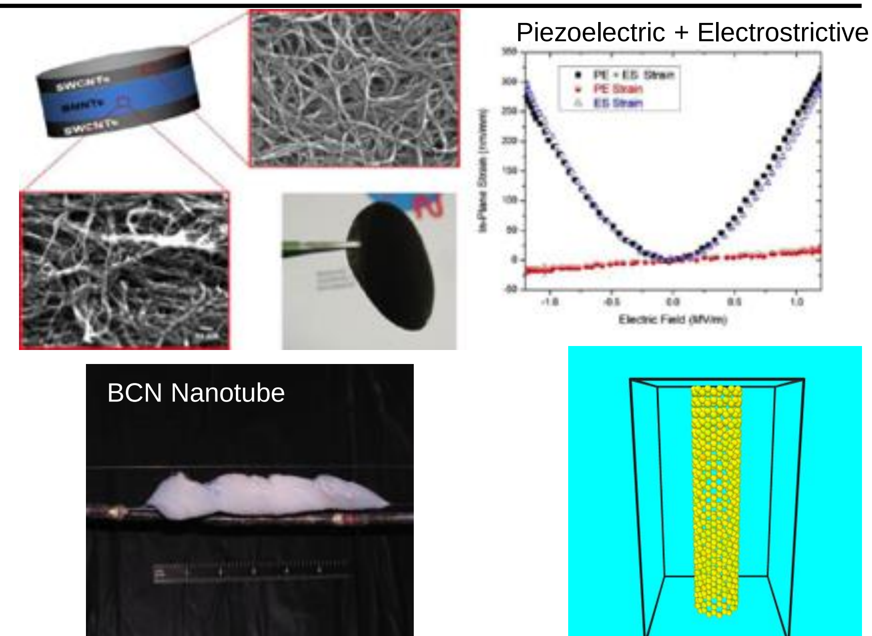
Flexible Structural TPS



Dispersion Processing



Sensor/Actuator/Energy



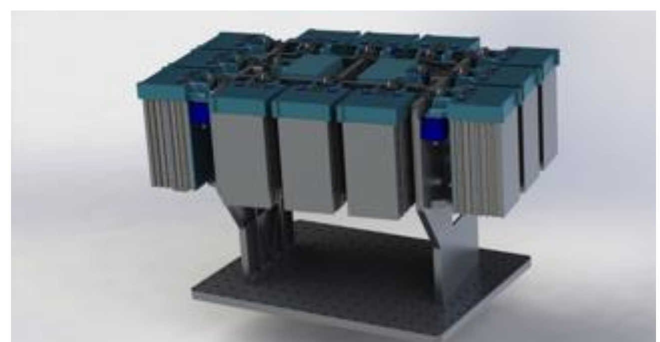
Materials International Space Station Experiment – Flight Facility (MISSE-FF)

HISTORY

- NASA Langley's MISSE & MISSE-X Programs directly led to MISSE-FF

FEATURES

- Launched in April 2018
- Permanent facility on outside of International Space Station (ISS)
- For testing materials and devices in the space environment
- Passive and active experiments
- Power and communications from ISS for active experiments
- Ram, Wake, Zenith, and Nadir orientations
- On-orbit photographs
- Modular experiment containers to be robotically deployed/retrieved
- Temperature, ultraviolet radiation, and contamination monitoring
- Long-duration space exposures
- Affordable, easy access to space
- 40% allocation for NASA
- 60% allocation for non-NASA
- https://www.alphaspace.com/

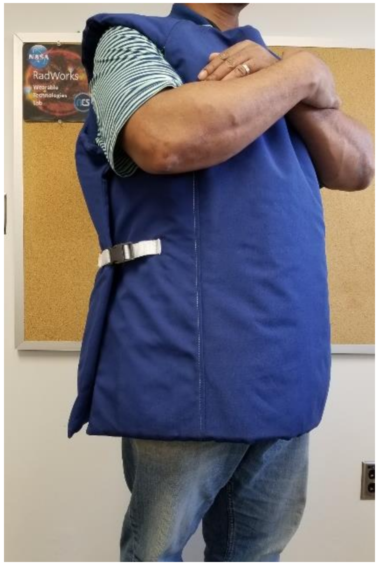


Materials International Space Station Experiment – Flight Facility (MISSE-FF), in open and closed positions. *Images with permission from Alpha Space Test & Research Alliance, LLC.*

Wearable Technology for Radiation Protection

Background

Astronauts need protection from intermittent large Solar Particles Events (SPEs). The Advanced Exploration Systems (AES) RadWorks Wearable Technology Team is designing garments that can be donned at the onset of an SPE and that will allow astronauts to move around the spacecraft continuing their work. Vital organ protection, preserving astronaut mobility, and minimizing parasitic mass are all being considered in designing a functional garment.



Project Objectives

- Develop an improved computational capability for evaluating the protection provided by radiation protection garments
- Assess the need for head gear to augment the protection provided by vests and evaluate design options
- Design and prototype an improved radiation protection vest:
  - Implement hydrogen-rich materials (e.g., polyethylene, Kevlar)
  - Optimal radiation protection areal density = 2 g/cm^2
  - Consider multifunctional designs to minimize parasitic mass
  - Human factors testing throughout the development process to preserve astronaut mobility

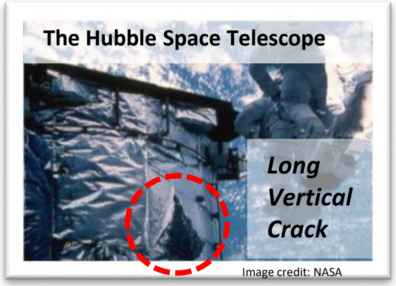
Bio-Inspired Space Environment-Resistant Polymer Composites

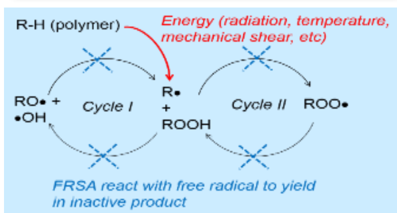
PI: Keith L. Gordon and Jin Ho Kang (Co-PI)

Goal/Gap

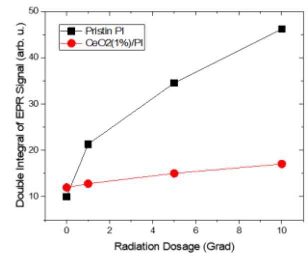
- Develop a novel space environment-resistant load-bearing polymer composite by incorporating bio-inspired *inorganic* free radical scavenging agents (FRSA).
- Lesson from nature: Plants protect themselves against solar UV radiation utilizing free radical scavenging capability of flavonoids or polyphenolics (i.e., α-tocopherol) to prevent molecular chain scission.
- However, the *natural* organic FRSA itself is plausible to be degraded at space environment, and a more stable FRSA in space is required.

Polymer Degradation in Space

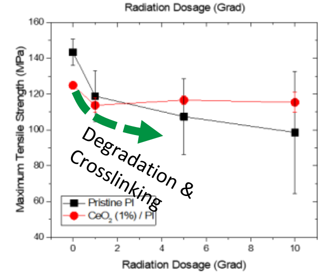




Electron Irradiation Test (60keV, @ MSFC)



Compared to pristine PI, CeO_2 doped PI showed the smaller change of EPR (electroparamagnetic resonance) signals under electron radiation. ***This indicates that CeO_2 nanoparticles suppressed the creation of free radicals!***

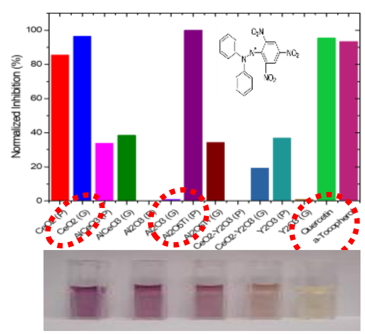


CeO_2 doped PI showed about ***4.5 times slower degradation*** compared to the pristine polymer at 10 Grad exposure, which means ***4.5 times longer service time*** can be expected without maintenance in space.

Technical Approach / Innovation

- Use of inorganic nanoparticles which have been recently explored for therapeutic purposes (cancer treatment) due to their strong free radical scavenging capacity.
- Selected inorganic nanoparticles (Al_2TiO_5, CeO_2) have been proven to show excellent free radical scavenging capabilities.
- Synthesis of nanocomposite (cyanate ester, bismaleimide, etc.) incorporated with nanoparticles and carbon fibers.
- Space environment resistant property is characterized under high energy radiation exposure (high energy electron, UV, γ-radiation, etc) via collaboration (MSFC, SNL).

Screening effective FRSAs



Active radicals → Radicals deactivated by FRSA

Partnerships: LaRC (Thibeault, Hinkley, Bryant, Wilkie), MSFC (Craven, Nehls, Vaughn), GRC (Kim De Groh), NIA, SNL

Accomplishments

- Confirmed enhanced radiation resistance of new composite material by simulated space environment test (electron, UV, gamma).

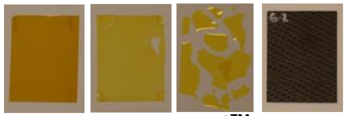
End of Year Deliverables

- Fabrication of space environment-resistant fiber reinforced polymer composite.

Next Steps

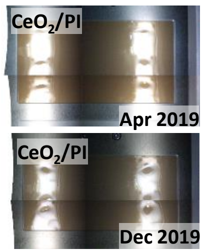
- Samples were successfully retrieved from MISSE 9, or are flying in orbit (MISSE 10), but need fund resources to complete the evaluation.
- Pursue funding to embed the new technology into mission.

Gamma Radiation Test (10 Grad, 1.33 & 1.17 MeV, ^{60}Co @ SNL)



CeO_2/PI | Pristine PI | LaRC™ CP1 | CeO_2/CF/BMI

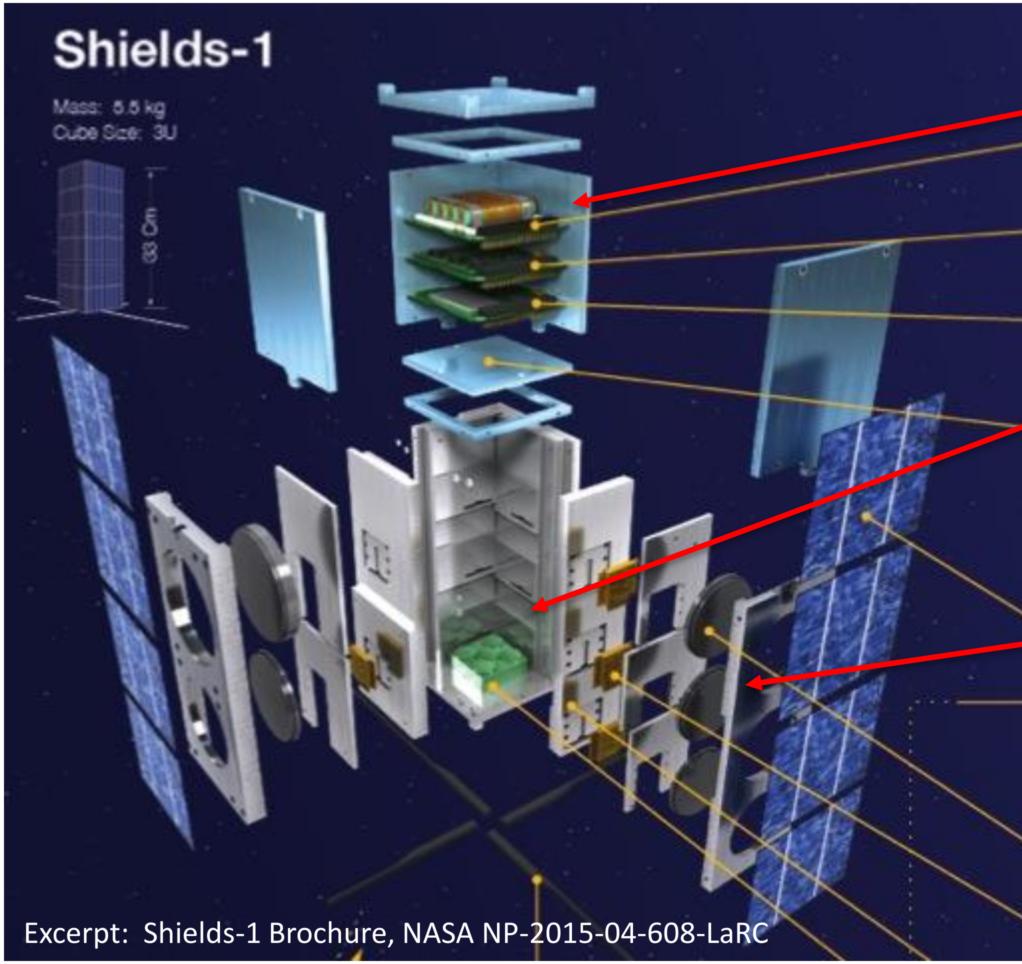
MISSE 9 (~8 months, Wake)



No visible change

Publications: LAR 19158-1, ASGSR 2018, MRS 2018, SACNAS 2018

Space Durable Hardware Experiments



Excerpt: Shields-1 Brochure, NASA NP-2015-04-608-LaRC

- **Vault Electronics**
  - **To measure total ionizing dose (TID) over time and monitor system electronics performance.**
- **Charge Dissipation Film Resistance**
  - **Measure the resistance over time**
- **Atomic Number (Z)-Grade Radiation Shielding**
  - **To measure total ionizing dose of Z-grade radiation shielding and compare to baseline aluminum for at least 3 samples each.**

Reference: D. Laurence Thomsen III, Wousik Kim, James W. Cutler, "Shields-1, A SmallSat Radiation Shielding Technology Demonstration", 29th Annual AIAA/USU Conference on Small Satellites, SSC15-XII-9, 8-13 August 2015, Logan, UT, p.1-7.

Langley Research Center ----

---- from the beginning!

2017 was NASA Langley Research Center's 100th Anniversary!