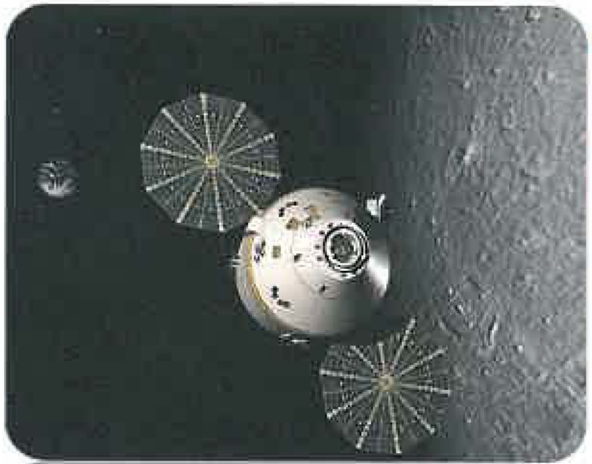
A Quick Overview of the Advanced Materials and Processing Branch

Dr. Robert G. Bryant – Branch Head
Dr. Catharine C. Fay – Assistant Branch Head
Dr. Terryl A. Wallace – Assistant Branch Head

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

Presenter: Cheol Park and Robert Bryant



NASA Langley at a Glance (2012)

Founded in 1917 as the first civil aeronautical research lab

~$853M PY2012 Budget
~$823M NASA Langley budget
~$30M External business

~3,600 Workforce
~1,900 Civil Servants
~1,700 Contractors (on/near-site)

Langley's Economic Impact (2011)
National economic output of ~ $2B and generates over 17,000 high-tech jobs
Virginia economic output of ~ $1B and generates over 9,000 high-tech jobs

Infrastructure/Facilities
788 acres, 169 Buildings
~$3.3B replacement value

Aeronautics
44%

Science
28%

Space Tech
15%

Human Exploration
12%

Education
1%

Cross-Agency Support Programs & Construction/Environmental Compliance & Restoration

Center Management & Operations
(Facilities, Fab, Engineering, Tech Authority, B&P, IRAD, Safety/Mission Assurance, Legal, Finance, Procurement, Human Resources)

Agency Management & Operations
(NASA Engineering & Safety Center, Office of Chief Engineer, Agency IT)

Construction/Env Compliance & Restoration
(Revitalization Plan)

RESEARCH DIRECTORATE (D3)

Jill M. Marlowe, Director
Damodar R. Ambur, Deputy Director
Steven G. Reznick, Deputy Director for Program Development
Vacant, Deputy Director for Facilities & Laboratories Ops.
Kenneth D. Wright, Assoc. Director for Resource Management
Vacant, Associate Director for Program Development
W. Allen Kilgore, Associate Director for Facilities Operations
Jerome T. Kegelman, Assoc. Director for Laboratories Ops.
Vacant, Executive Secretary

Safety

Roger L. Wagner, Sr. Safety Eng.
Charles Zeitman, Safety Eng.

Chief Engineers (CE) & Tech Leads

Joel L. Everhart, CE of Adv. Capabilities
Peter F. Jacobs, CE for Test Ops Excellence
John Korte, CE for Hypersonics
Laurence D. Leavitt, CE for Aerodynamics
J. Ransom CE for Materials & Structures
Richard J. Silcox, CE for Acoustics
Brenton Weathered, CE for Airborne Systems
William Winfree, CE for Measurement Sciences
Edward R. Generazio, Agency NDE Specialist
John R. Micol, Lead for Business Partnership
Steve Syrett, Senior Project Portfolio Manager
Daniel M. Vairo, Fac. & Lab Investments Mgr.

Resource Management Team

Yvonne W. Beyer, ATP Bus. Mgr.
Jessica B. Henegar, Jr. Prg. Analyst
Lori S. Rowland, Bus. Mgr.
Jennifer M. Schuetz, Prg. Analyst
Vacant, Program Analyst

Jamie W. Godsey, IT Manager
Peter Kjeldsen, Program Specialist

Lori W. Brown, Sr. Adm. Officer
Jennifer L. Frost, Adm. Officer
Bonnie J. Lumanog, Adm. Officer
Tracey L. Patterson, Adm. Officer

L. David Wall, TEAMS II Center Mgr.
Marisol E. Garcia, NIA COR
Dexter L. Blackstock, SMAART COR

D301 Configuration Aerodynamics Branch
Zachary T. Applin, Head
Sally A. Viken, Asst. Head

D302 Computational Aero-Sciences Branch
Joseph H. Morrison, Head
Vacant, Asst. Head

D303 Flow Physics and Control Br
Catherine B. McGinley, Head
Luther Jenkins, Asst. Head

D304 Advanced Sensing & Optical Measurement Branch
Tom Jones, Head
Wm. M. Humphreys, Acting Head & Asst. Head

D305 Aerothermodynamics Br
N. Ronald (Ron) Merski, Head
William A. Wood, Asst. Head

D306 Hypersonic Airbreathing Propulsion Branch
Kenneth E. Rock, Head
Shelly M. Ferlemann, Asst. Head

D307 Advanced Materials & Processing Branch
Robert G. Bryant, Head
Catharine C. Fay, Asst. Head

D308 Aeroelasticity Branch
Stanley R. Cole, Head
Boyd Perry III, Asst. Head

D309 Durability, Damage Tolerance, & Reliability Branch
Jonathan B. Ransom, Head
Ed Glaessgen, Asst. Head

D312 Structural Mechanics & Concepts Branch
David N. Brewer, Head
Sandra P. Walker, Asst. Head

D313 Nondestructive Evaluation Sciences Branch
K. Elliott Cramer, Head (Detailed)
D. Michele Heath, Acting Head & Asst. Head

D314 Aeroacoustics Branch
Charlotte E. Whitfield, Head
Vacant, Asst. Head

D316 Dynamic Systems & Control Branch
Carey S. Buttrill, Head
Vacant, Asst. Head

D317 Flight Dynamics Branch
C. Mike Fremaux, Head
Gautam H. Shah, Asst. Head

D318 Crew Systems & Aviation Operations Branch
Lisa O. Rippy, Head
Steven G. Velotas, Asst. Head

D319 Electromagnetics & Sensors Branch
Erik Vedeler, Head
Sandra V. Koppen, Asst. Head

D320 Safety-Critical Avionics Systems Branch
Raymond S. Calloway, Head
A. Terry Morris, Acting Asst. Head

D321 Structural Acoustics Branch
Kevin P. Shepherd, Head
Randolph H. Cabell, Asst. Head

D322 Structural Dynamics Branch
W. Keats Wilkie, Head
Vacant, Asst. Head

D325 Materials Experiments Br
Kelly S. Tarkenton, Head

D326 Structures Experiments Br
R. Scott Young, Head

D327 Subsonic/Transonic Testing Branch
Hubert H. Senter, Head (Detailed)
Frank P. Quinto, Acting Head
D327A Richard D. White, Asst. Hd.

D328 Supersonic/Hypersonic Testing Branch
Michael Difulvio, Head
D328A David S. Aliff, Asst. Head
D328B Lynn D. Curtis, Asst. Head

D329 Structures Testing Branch
Lisa E. Jones, Head
D329A George E. Palko, Asst. Hd.

D330 Technologies Application Branch
Michael A. Chapman, Head
Shawn R. Britton, Met. & Calibration Prog. Std Practice Eng.

D331 Revolutionary Aviation Technologies Branch
Scott D. Holland, Head

Advanced Materials and Processing Branch
5+ Facilities : Offices and Laboratories


B1293A


B1267


ISS


B1293C


B1148


B1205

The Future of Materials for NASA

Mission Statement : *"To Develop Advanced Materials and Processes that Expand the Engineering Design Space to Enable NASA Missions."*

- **Reduction in areal densities of load bearing structures requires the combination of all three material classes: Polymers, Metals, and Ceramics**
  - Reduce amount and traditional use of mechanical fasteners
  - Make bondlines and welds stronger than the weakest parent material
  - Directly insert the correct material where it is needed
- **The increased efficiency of solid state device technology requires the combination of all three material classes: Polymers, Metals, and Ceramics**
  - Decrease material defects and increase operating temperature ranges
  - Increase control of multifunctional properties
  - Directly insert the correct material where it is needed

➢ **To achieve this, AMPB needs to continue investing in 4 fundamental core technical areas:**
  - New Materials through **Synthesis** (Composition of Matter)
  - New Materials through **Processing**
  - **Characterization** of Materials
  - **Computational** Modeling and Lifing of Material Interactions

AMPB : New Materials through Synthesis

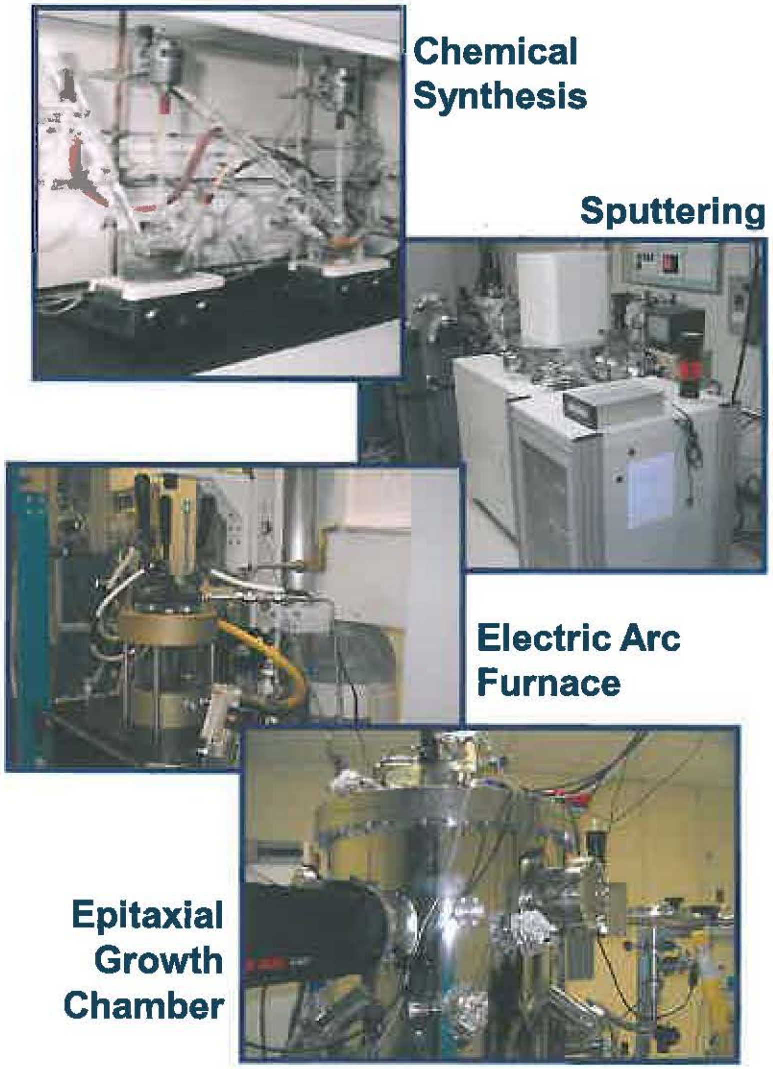
Physical Science Centric Discipline

"The manipulation of atoms and molecules to produce new materials. Includes the development of new synthetic techniques and methodology, and equipment modification and customization."

Academic Disciplines include Chemistry, Physics, Ceramics, Metallurgy, and Materials Science.

Technologies are resins (solid and liquid), metal alloys, ceramic solid solutions, coatings, adhesives, nanomaterials, molecularly engineered materials, elastomers, "active/smart" materials.

Products are powders, pellets, ingots, solutions, wafers and other stock forms of materials ready to be processed into test specimens.



AMPB : New Materials through Process

Engineering Centric Discipline

"The creation of new materials through the processing or combining of stock materials into new forms. Includes the development of new fabrication techniques and technology."

Academic Disciplines include Chemical, Ceramic, Polymer, Mechanical, and Metallurgical Engineering.

Technologies are processing parameter control, novel fabrication methods, scalable processes, new hybrid materials, bonding and joining technology, extrusion/injection surface engineering and preparation, and equipment design and modification.

Products are particulate, fiber and laminated reinforced composites, films, membranes, engineered surfaces, electrical, optical, and mechanical devices, and prototype structures.

Composites

Ceramics

Plasma Spray

EBF^3

AMPB : Characterization

Physics Centric Discipline

"The analysis of material properties at scales from atomic through bulk. Includes instrument design, statistically based data reporting, and new test method development and validation."

Academic Disciplines include Chemistry, Physics, Microscopy, and Materials Science.

Technologies are customized analytical equipment, unique property test-data sets, streamlining of verification procedures, forensic failure analysis, validation of new test methodologies.

Products are highly accurate and precise data, quality specimen development, unique analytical methods, accurate lifecycle testing, and a fundamental understanding of material properties and composition as tied to synthesis and processing.

Microscopy

Spectroscopy

Thermal Analysis

Mechanical Testing

AMPB : Computation

Numerical Methods Centric Discipline

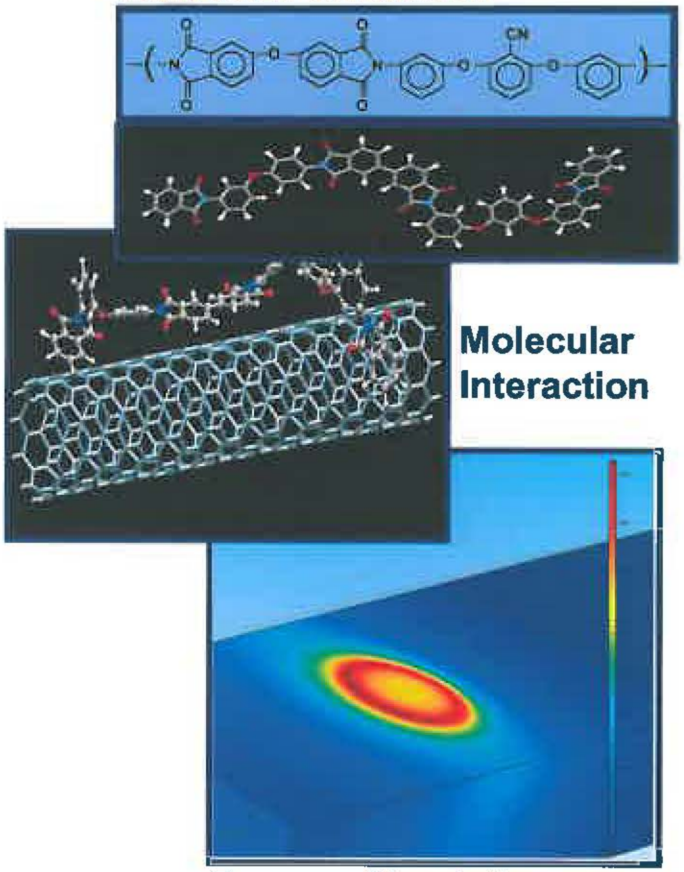
"The use of computation to simulate and predict the behavior and interactions of materials from synthesis and processing through lifing. Includes the input of experimental data and the development of computational and process control algorithms."

Academic Disciplines include Computer Science, Physics, Mathematics, and Computer Engineering.

Technologies are Interactive machine codes, database of experimental inputs and material properties, reduction in the amount of experiments to develop a new material or validate a result.

Products are faster development of new materials, process control algorithms, faster computational methods, increased predicative lifing capabilities, and the development of a Virtual lab.

Molecular Simulation



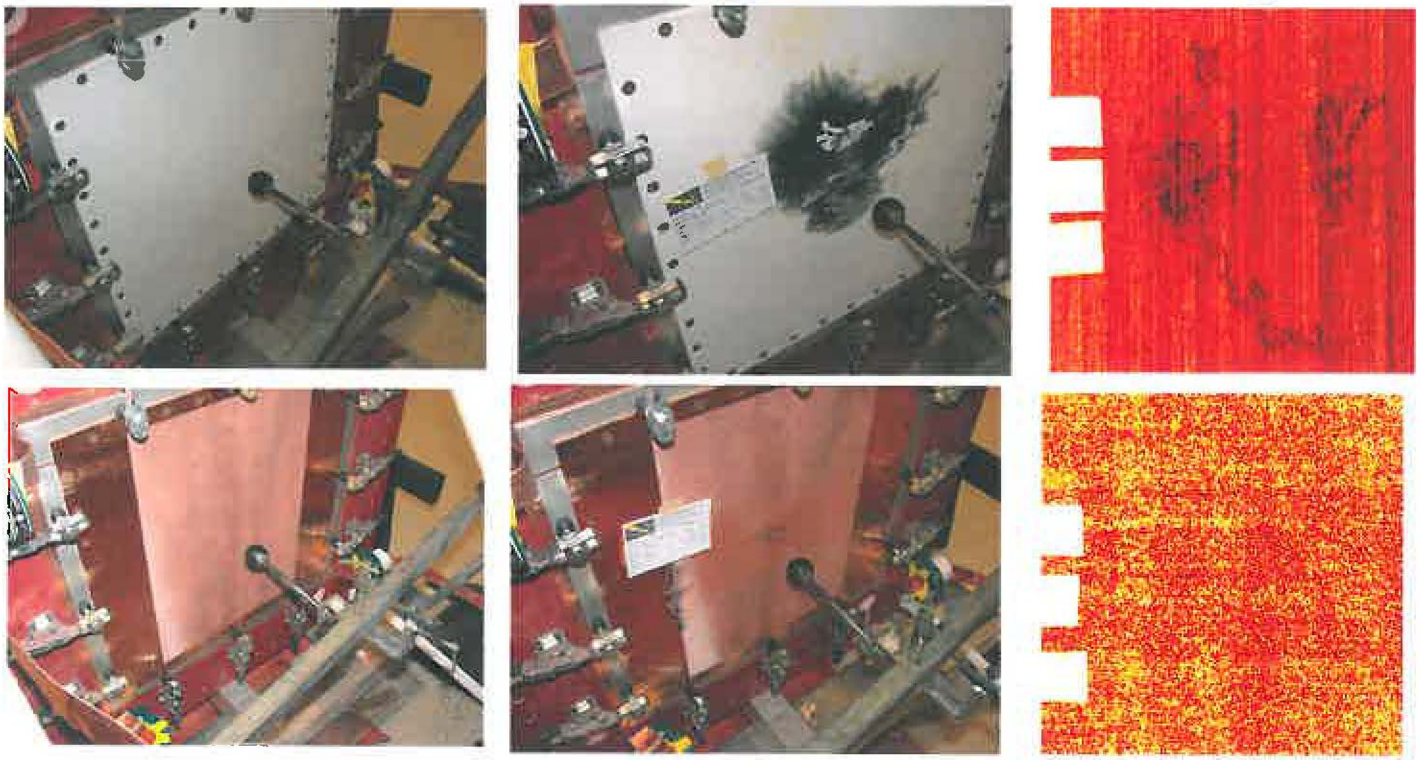
Molecular Interaction

Process Simulation and Control

Technical Capabilities/Instrumentation

- **Materials Synthesis**
  - Chemical (small molecule)
  - Polymer (macromolecule)
  - Metallic Alloys
- **Materials Processing**
  - Prepreg and Composite any resin/fiber)
  - Solution film casting/melt extrusion
  - Vac Press, VARTM, Autoclave, ATP
  - Plasma Spray
  - EBF3
  - Bonding/Joining
  - Heat treatment Vac. Furnaces
  - Sputtering/PVD
- **Mechanical**
  - Electromagnetic/servo-hydraulic load-frames (Liq. He to 3000F to 10-7T
  - Small Ball-screw frames w/ E-Chambers
  - Pin-on-disk Tribometer w/ furnace
  - Tabor Abrader
- **Analytical**
  - SEM/TEM/HR-SEM/SEMs – Variable Pressure Lg chamber (w/ EDX, WDS, µ-probe, load frame, EBSD/AFM tips, EELS, SIMS)
  - Thermal Analysis (DSC/TGA/TGA-MS/DMA/TMA/Laser Flash/Heat Flow/Rheometers)
  - Spectroscopy (NMR/IR/near-IR/UV-Vis/RAMAN//XRD/Elipseometer)
  - Chromatography (GPC/GC-MS)
  - Surface Analysis (Droplet and Insertion instruments for surface tension/optical profilometer /SPM/Nitrogen Absorption
  - Optical Microscopy (Confocal/ Fluorescence/Metallograph/X-Polarized

VARTM PMC Metal Hybrid Panels for Lightning Strike Protection: Initial Testing



Before Strike

After Strike

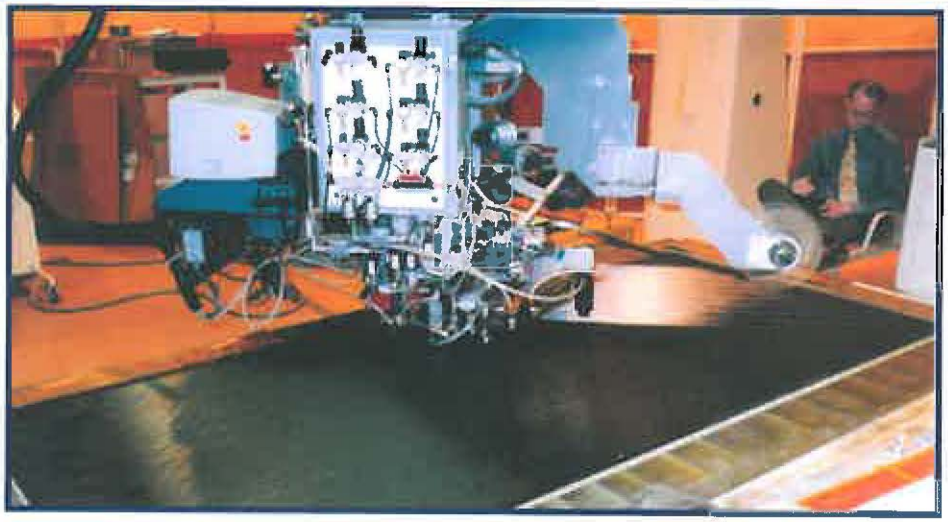
X-Ray

SOA DEXMET – Cu Mesh over PMC

PMC-Metal Hybrid fabricated at LaRC

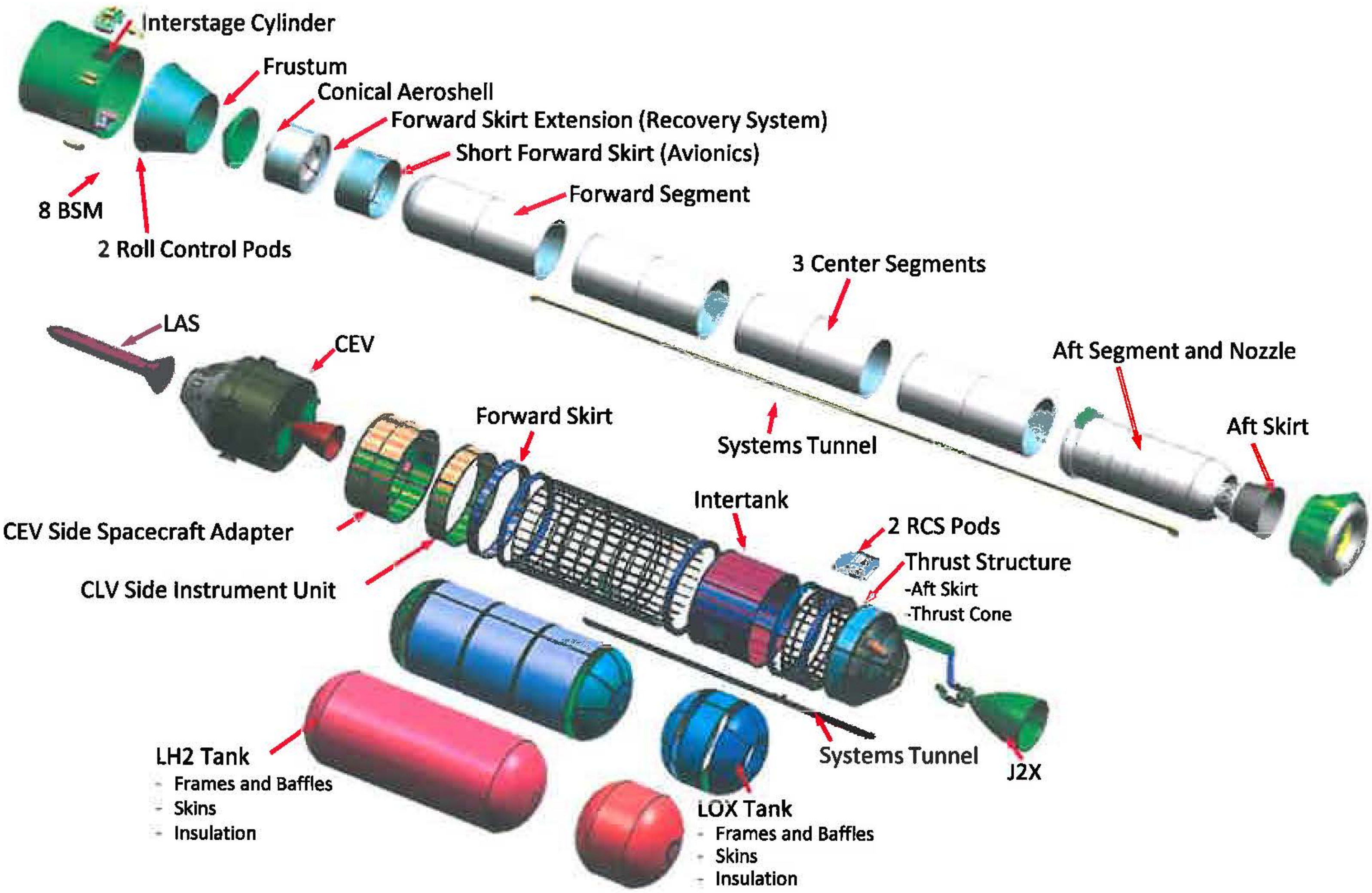
- In trial testing of a glass fabric plasma coated layer secondarily bonded to an IM7/8552 PMC:
  - The strike of the PMC-Metal Hybrid was very dispersive and spread the currents thru multiple paths.
  - Plasma coated PMC exhibited similar displacement and damping characteristics as the SOA DEXMET panel (3mm to 0 in 350ms)
  - Unlike the SOA DEXMET, the plasma coated Hybrid lost <u>no</u> conductivity during the test

HH-ATP of High Performance Thermoplastics



- Heated Head Automated Tape Placement is a PMC fabrication technology which offers the potential to fabricate high performance thermoplastic matrix composites out-of-autoclave
  - Engineering Thermoplastics such as PEEK, PEKK, and PPS have significant advantages over Thermoset matrices such as epoxy and BMI
    - Higher Toughness, reducing knockdown associated with CAI.
    - Comparable Use Temperatures.
    - No out-life or shelf-life issues
    - Potential for recycling
- Since the adoption of toughened epoxy PMCs in the 1990's by the major airframers, thermoplastic PMCs have found limited use as primary structure on 777 or 787. This is due in large part to the increased manufacturing cost associated with fabrication using these materials. The HH-ATP fabrication process addresses this issue
  - In 2010, M&P engineers at BOEING, ATK, and LHM commented that their companies had ongoing research projects to lower the cost of fabricating thermoplastic matrix PMCs for both primary and secondary structure on future aircraft
  - Airbus is using thermoplastic PMC on the leading edge of the A380

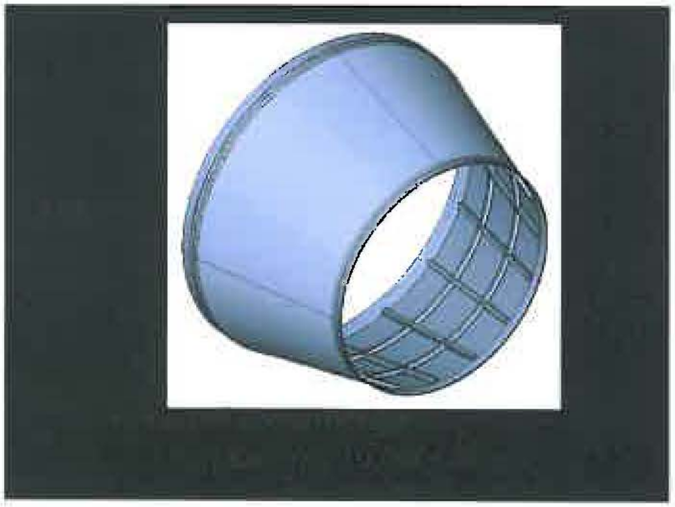
Technology Maturation and Insertion



Technology Maturation and Insertion

Transferring Innovative Manufacturing Methods to Industry

Typical Frustum ← → Near Net Shape Cone



- Single Piece Construction
  - Part Count = 1

Near Net Shape Forming of Conical Structures

Status

- Proven technology for steel
- Apply expertise to Al & Al-Li alloys
- 44" Subscale Al trial, 10/08

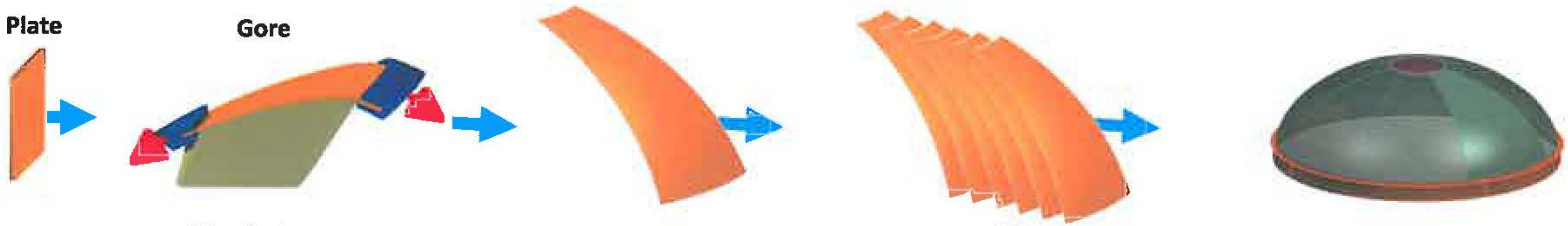
Benefits

- Increased reliability: elimination of rivets
- Reduced part count & touch labor
- Reduced NDE
- Potentially scalable to Orion CM

Technology Maturation and Insertion

Cryogenic Tank Dome Manufacturing

Traditional Approach



Plate

Gore

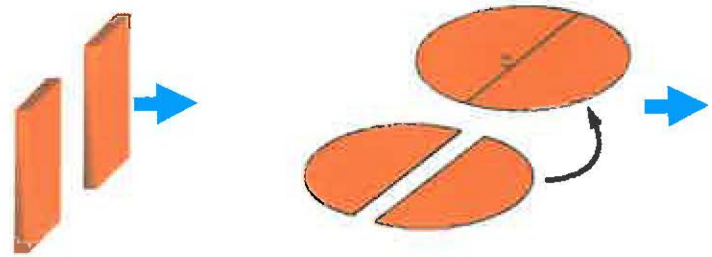
Mandrel

Dome Gore Panel

Dome Gores

Welded Gore Assy. Dome

Developmental Approach



Plate

FSW dome blank

Spin forming process

Spun Formed Dome

Status:

- Joint ETDP / ARES I Task
- Assessment of friction stir welded blanks in progress
- 1 m sub-scale spun dome – July 08
- 5 m full-scale demonstration spun dome - Feb 09

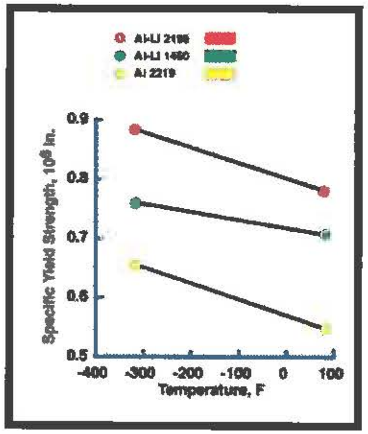
Benefits:

- Improved reliability / safety
  - Eliminates up to 9 major welds and associated weld lands
- Reduced part count and touch labor
- Reduced inspection costs

Friction Stir Weld – Spin Formed Dome Technology Merits

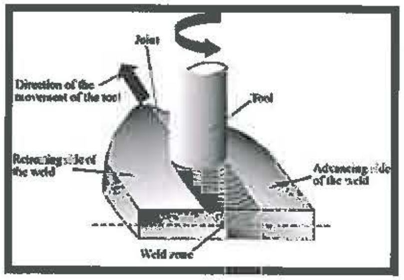
Aluminum-Lithium Alloys

- High strength / weight ratio
- Good SCC resistance

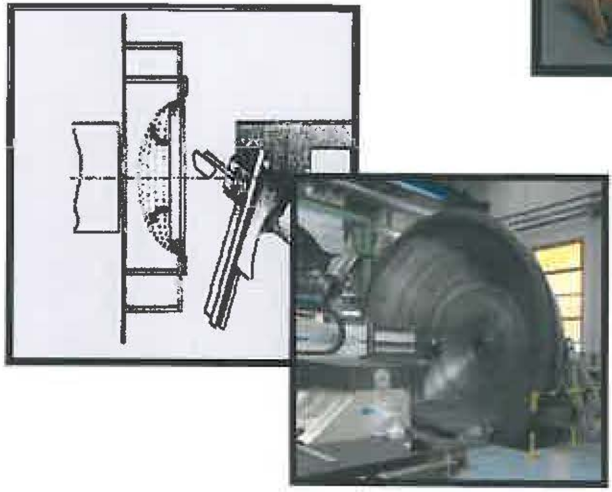


Friction Stir Welding

- Greater strength & ductility than fusion welding
- Low defect occurrence



FSW Spun Formed Dome
5 m dia. Al-Li 2195



Spin Forming

- Single piece near net shape manufacturing
- Lower manufacturing costs
- Improved mass fraction
- Improved system reliability

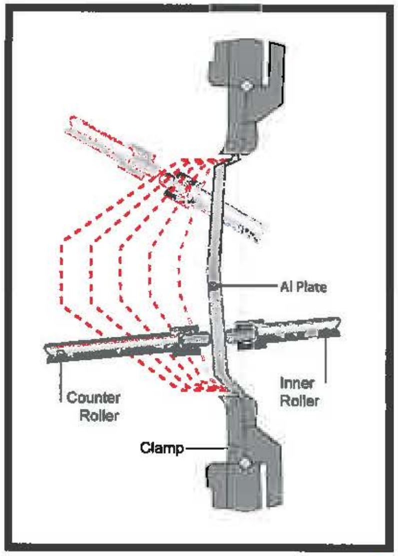
Adaptable, Low Cost Tooling
NASA LaRC, MT Aerospace

Aluminum Forming

First successful Aluminum Dome, Oct. 2011

As-formed, no machining
0.6m dia.

Demonstrate with complex geometry

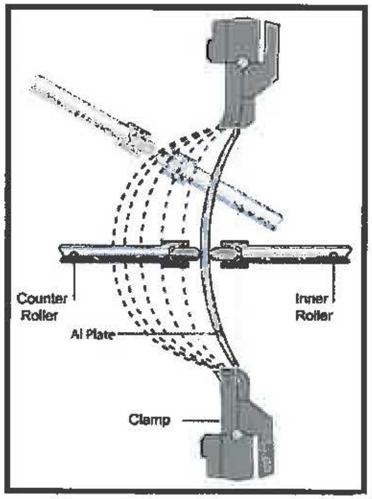


First successful Aluminum Crew Module, May 2012

Commercially Produced Titanium Dome

As-formed, no machining
~2m dia.

Counter Roller Process



Scale up to Full Size Component

Innovative Cryotank Fabrication
NASA LaRC, Leifeld, MT Aerospace

Al-Li Trial

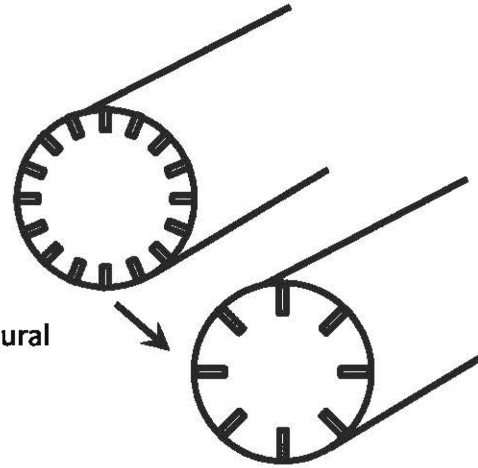
$50K

Successful forming of Al-Li 2195

Oct. 2011
0.3m dia. part

Scale-up to 1 meter dia., optimize stiffener design/spacing

$150K

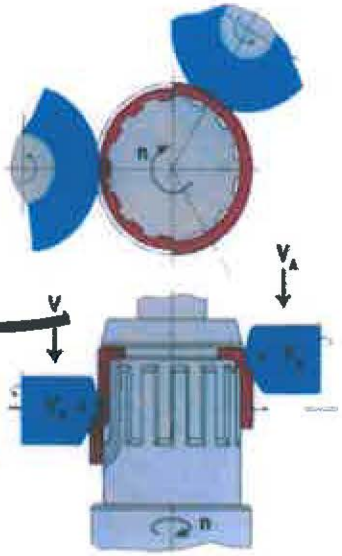


Increased structural efficiency

Scale Up to Full Size Barrel

External Tank LH_2 Barrel Assembly

Integrally stiffened cylinder process



Commercially produced steel clutch housing

As-formed
No Machining
0.3m dia.

Laser Ablation Patterning for Adhesion Promotion

A Nd:YAG laser removes (ablates) surface material in a controlled fashion. The ablation depth can be controlled by variation of laser power, frequency, and scan speed. Exact parameters for ablation are material dependent. Result is an increase in surface energy and higher bond strength without generating extraneous debris.

Pattern Visualization

90° cross-hatch pattern

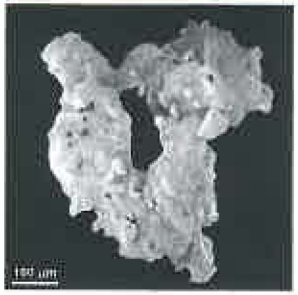
A pattern of line series oriented at rotating 90° intervals,similar to a Peel-

Superhydrophilic surfaces are created

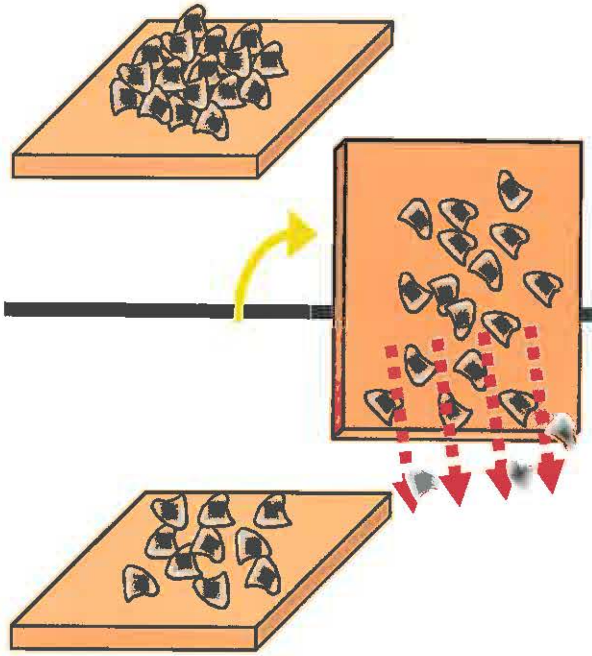
Result is a stronger bond

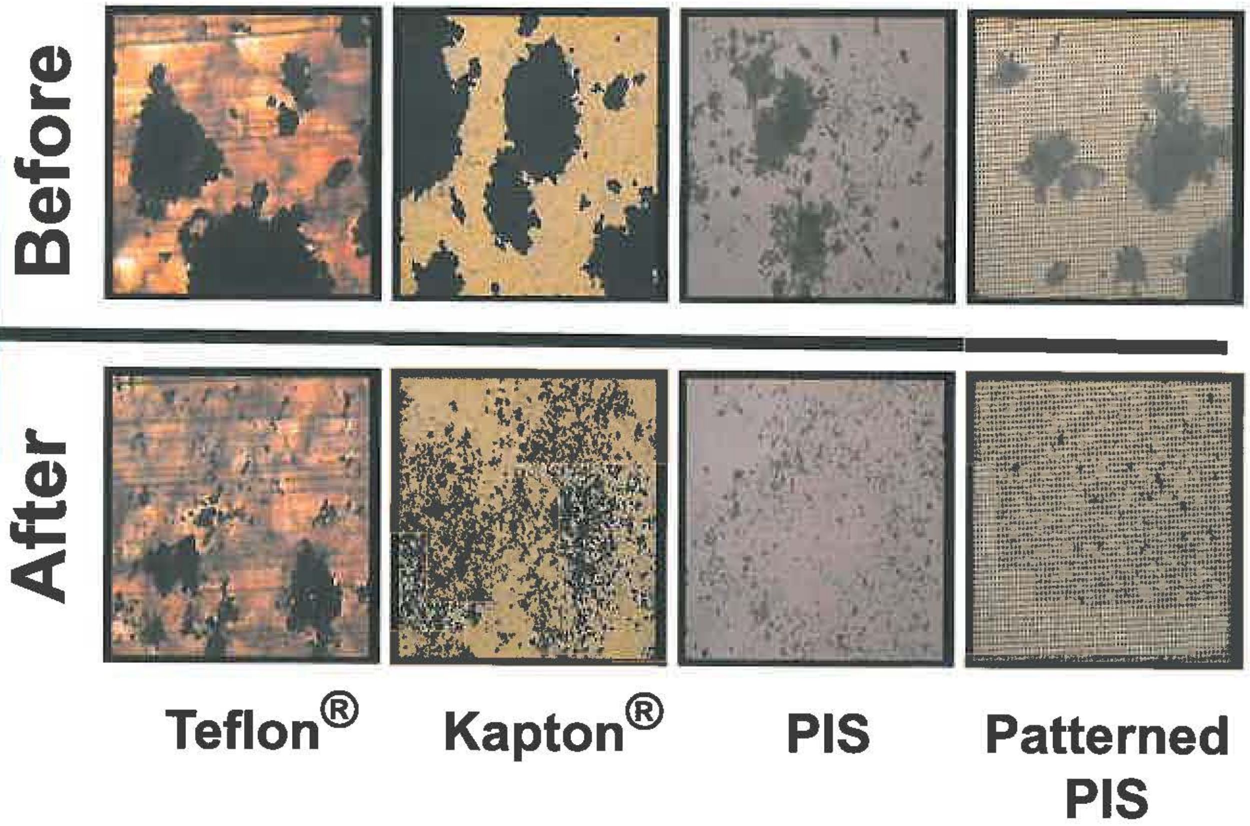
Result is that bond strength increases ~15% and failure mode moves into the composite

Laser Ablation Patterning for Adhesion Prevention



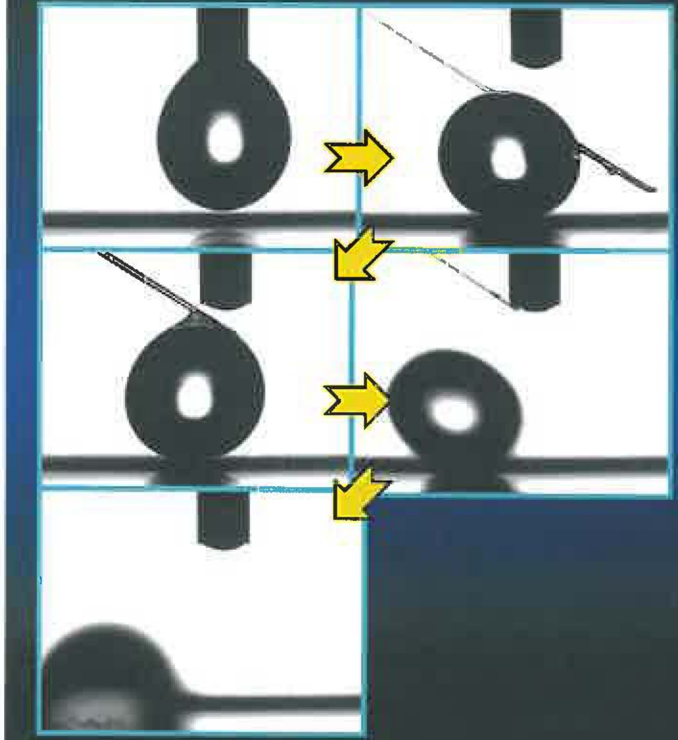
Lunar dust (regolith) stimulant





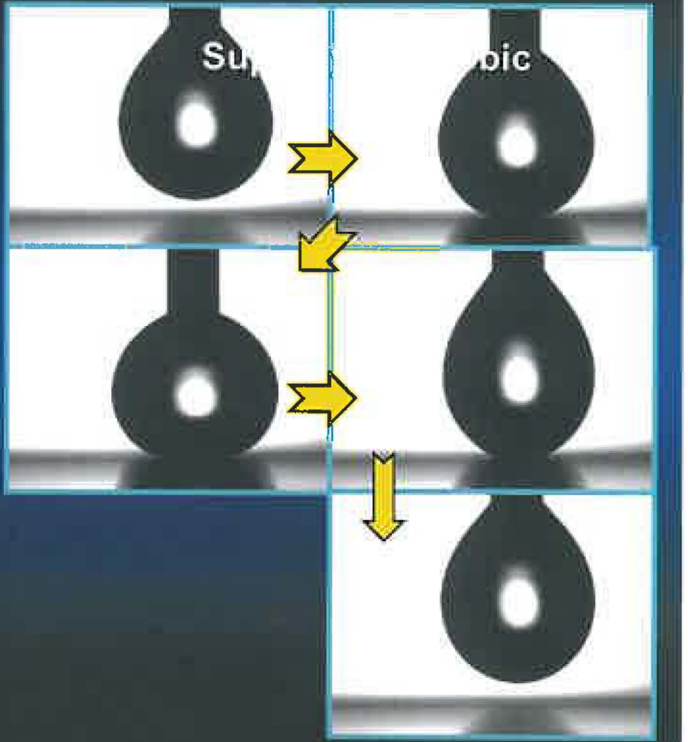
Laser Ablation Patterning on Different Substrates for Self-Cleaning and Antifouling Surfaces

Polyimide Siloxane



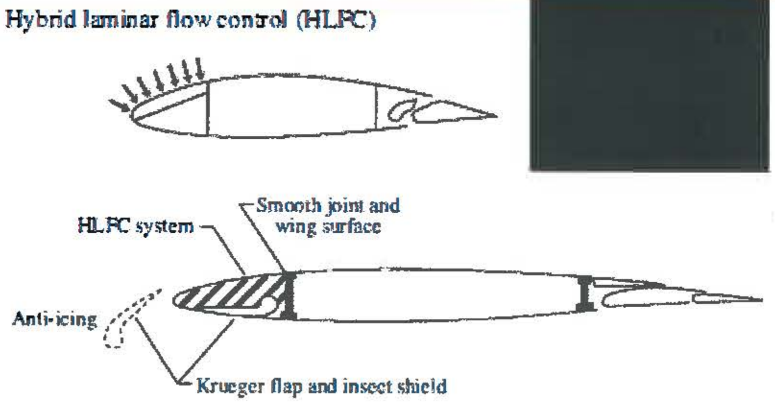
Cassie-Baxter state

Polyimide butadiene-acrylonitrile

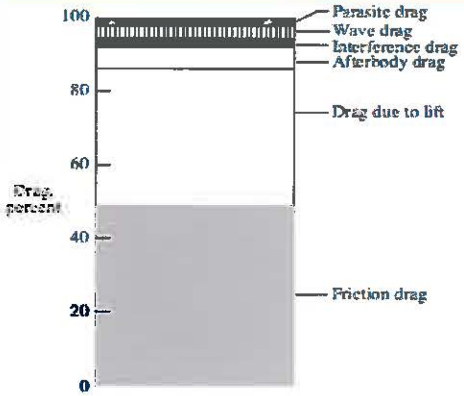


Trapped air between pillars helps prevent droplets from spreading resulting in Superhydrophobicity

Mitigation of Insect Residue on HLFC Leading Edge Surfaces



SOA Insect Residue Alleviation System on HLFC Surface



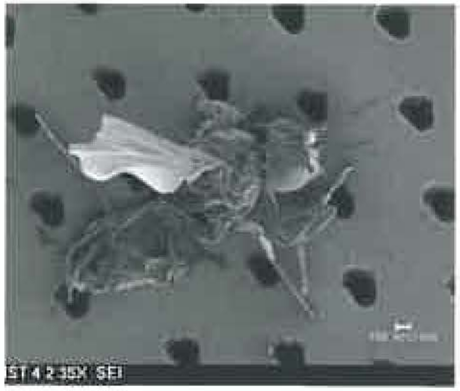
R.D. Joslin, "Overview of Laminar Flow Control", NASA/TP-1998-208705

Why is insect residue important?

- A small percentage of vehicle drag
- Can disrupt laminar flow
- Results in increased fuel usage

Consequence:

- Need to carry extra fuel
- Reduced cargo capacity
- Higher ticket and transportation costs



Impacted insect adhesion & blockage of HLFC surface

D. O'Donoghue, T.M. Young , J.T. Pembroke, T.F. O'Dwyer, "An investigation of surfactant and enzyme formulations for the alleviation of insect contamination on Hybrid Laminar Flow Control (HLFC) surfaces", Aerso Sci Tech, 6 (2002) 19-29.

Problem:

Adhesion of insect hemolymph (adhesive) and impacted insect (biological adherend) to HLFC leading edge (i.e. aluminum or composite adherend).

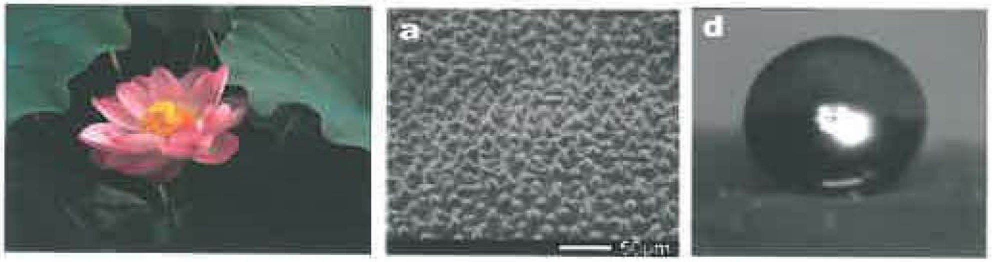
Objective:

Eliminate all insect residue on HLFC leading edge and/or easy removal of remaining residue after landing through the use of a coating. Other concerns include ease of application, practical real world use, and durability to operational environment.

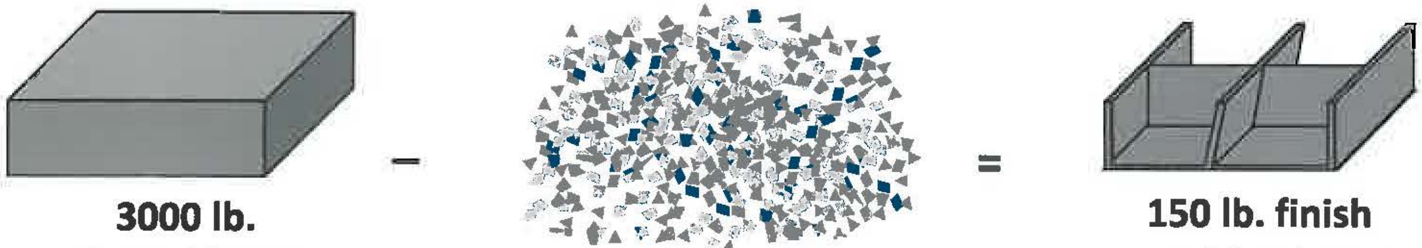
Approach Combining Coatings and Surface Engineering

- Use combination of coating chemistry and surface engineering to enhance resistance to insect residue adhesion
  - Abhesive coatings
    - Non-stick coating is based on the coating having very low surface energy as measured by contact angles.
    - Various coatings with low surface energy and hydrophobic characteristics will be used.
    - Coatings will be modified to prevent bug residue coagulation
  - Surface engineering
    - Controlled roughness of surfaces has been shown to enhance hydrophobicity. This approach may be used to to enhance abhesive characteristic of the surface as well.
- Test methods will be developed to simulate bug contamination during flight to screen candidate coatings.

Classification	Contact Angle	Example
Hydrophilic	θ< 90	
Hydrophobic	150>θ> 90	
Super-Hydrophobic	θ> 150	



EBF^3 Manufacturing Process



3000 lb. forged billet – **2850 lb. chips** = **150 lb. finish machined part**

20 : 1
buy-to-fly

Additive Manufacturing via EBF^3:

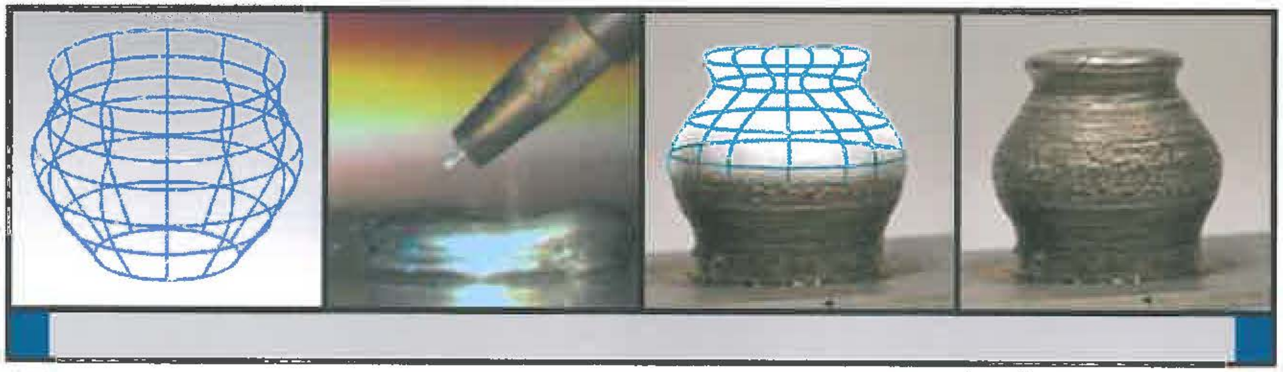
200 lb. rolled sheet + **100 lb. wire** + **EBF^3** – **150 lb. chips** = **150 lb. finish machined part**

2 : 1
buy-to-fly

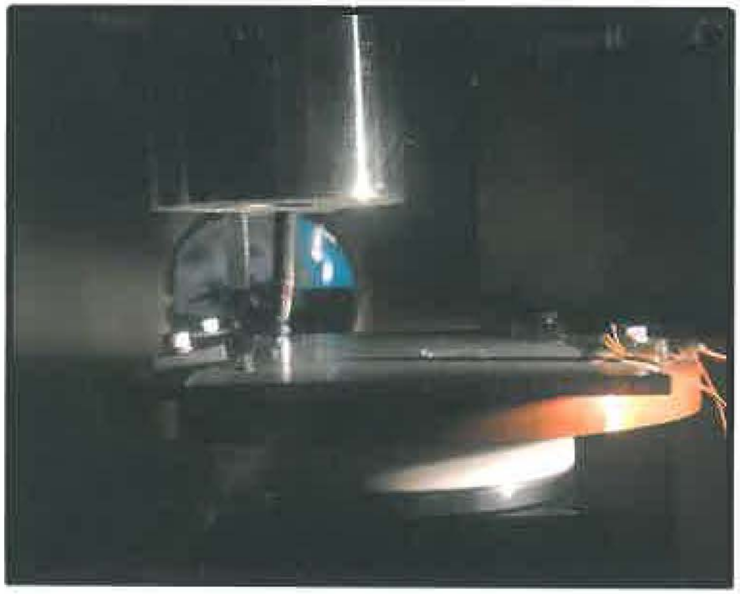
EBF^3 saves significant resources over current methods:
raw materials, energy, fewer chemicals (cutting fluids), lead time = cost

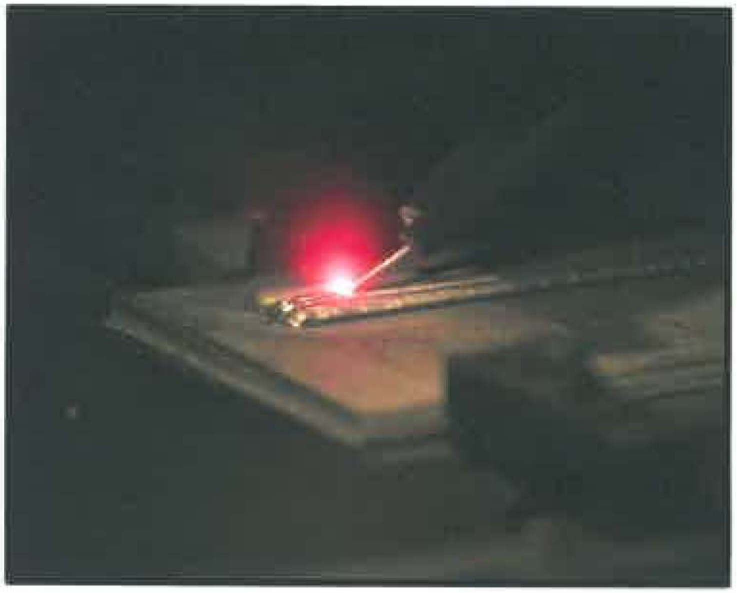
EBF^3 Build Process

EBF^3 System in ISPR



Initialize → Build → Control → As-Built





Positioning Ourselves for the Future

Emerging Technologies - Enabling Novel Multifunctional Structures

Designed for Assembly

Built-up Structure

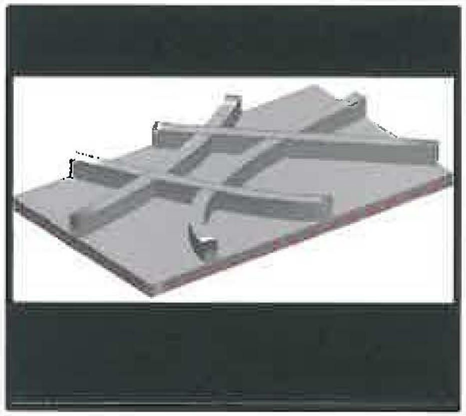
- Skin and stiffeners machined from plate
- Multiple parts and fasteners
- High: cost, scrap, weight, and assembly time

Integrally Stiffened

- Skin machined from sheet
- Integrated with near net stiffeners (SPF, extrusions, etc.)
- Replace fasteners (FSW, RSW)
- Reduce: cost, weight, parts, fasteners, assembly time

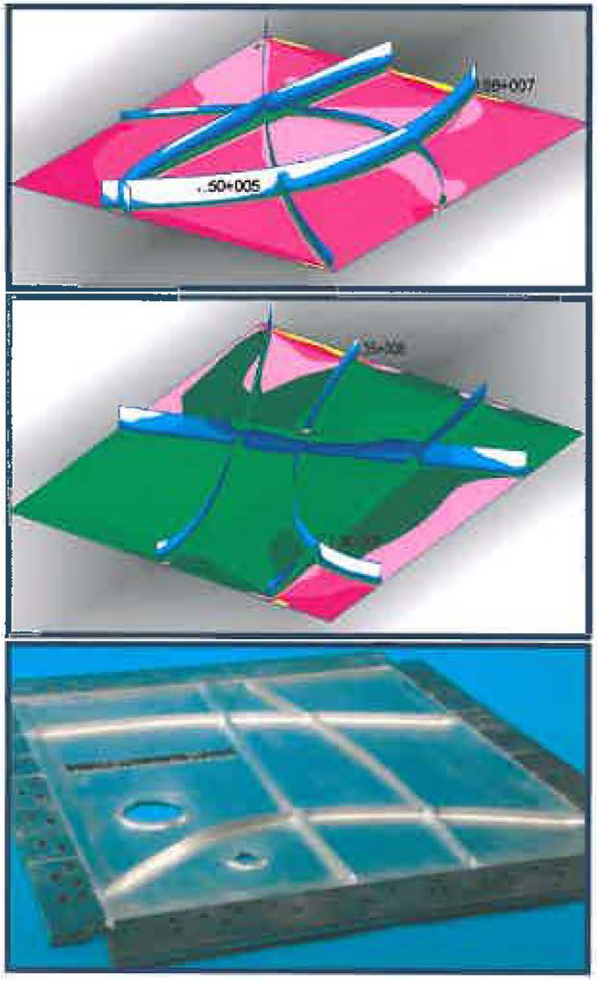
Designed for Performance

Unitized Structure



- EBF3 combines fabrication of material+structure
- Enhanced performance through multi-functional novel design
- Minimize: scrap, weight, fasteners, assembly time

Optimized Structural Design



Structurally optimized panel designs & machined test panel

Funder

NASA Aeronautics – Fixed Wing & Supersonics Projects

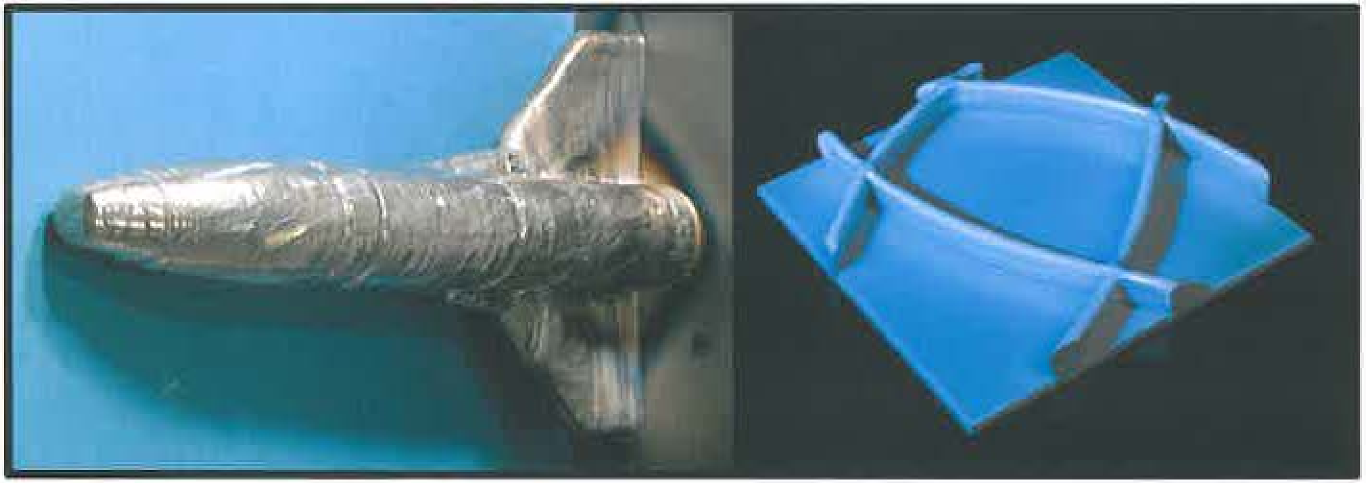
Challenge

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

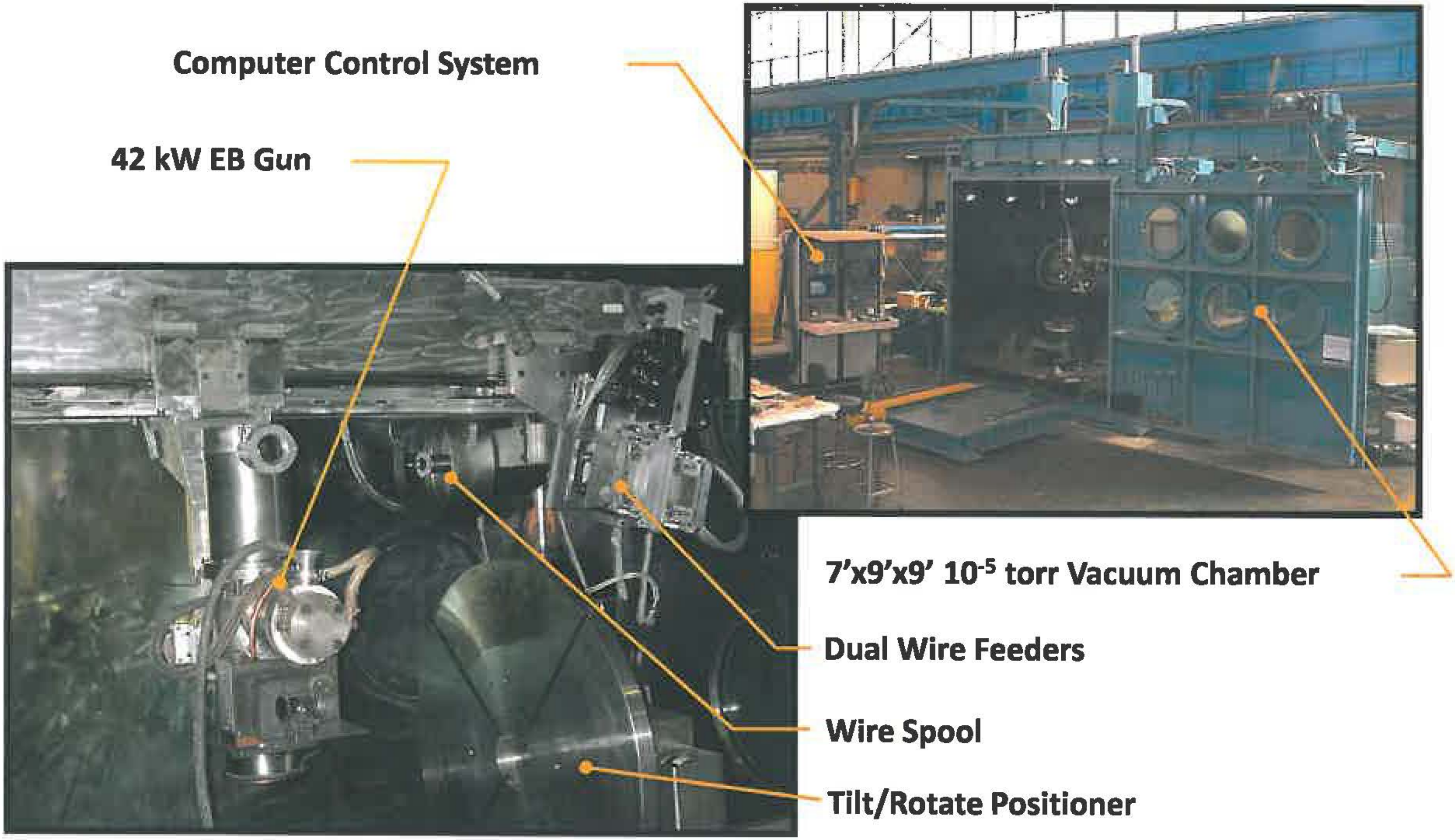
Current Work

- 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

Sample EBF^3 Parts



Ground-Based EBF^3 System at NASA LaRC



Computer Control System

42 kW EB Gun

7'x9'x9' 10^{-5} torr Vacuum Chamber

Dual Wire Feeders

Wire Spool

Tilt/Rotate Positioner

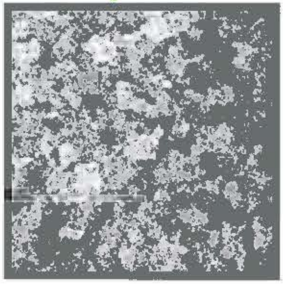
History of EBF^3 Development

Technology Inception

Define EBF^3 system specs

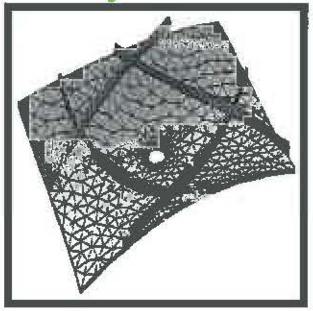
EBF^3 system installed at NASA LaRC

Technology Maturation



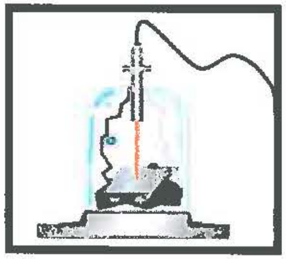
EBF^3 process understanding

Increasing part complexity



Unitized & graded structures

Design portable EBF^3 system



Integrate prototype portable EBF^3 system

Microgravity testing

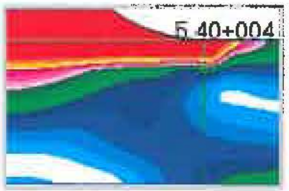
Patent on portable EBF^3 concept issued 1/07

Future of EBF^3

Commercialization

Current Applications

Influence Future Designs



Computationally guided process maturation

First production parts on aircraft

Selective reinforcement/ integrated sensors

2007 2008 2009 2010 2011 2012 2013 & beyond

Detailed property testing for certification

Process certified

2007 2008 2009 2010 2011 2012 2013 & beyond

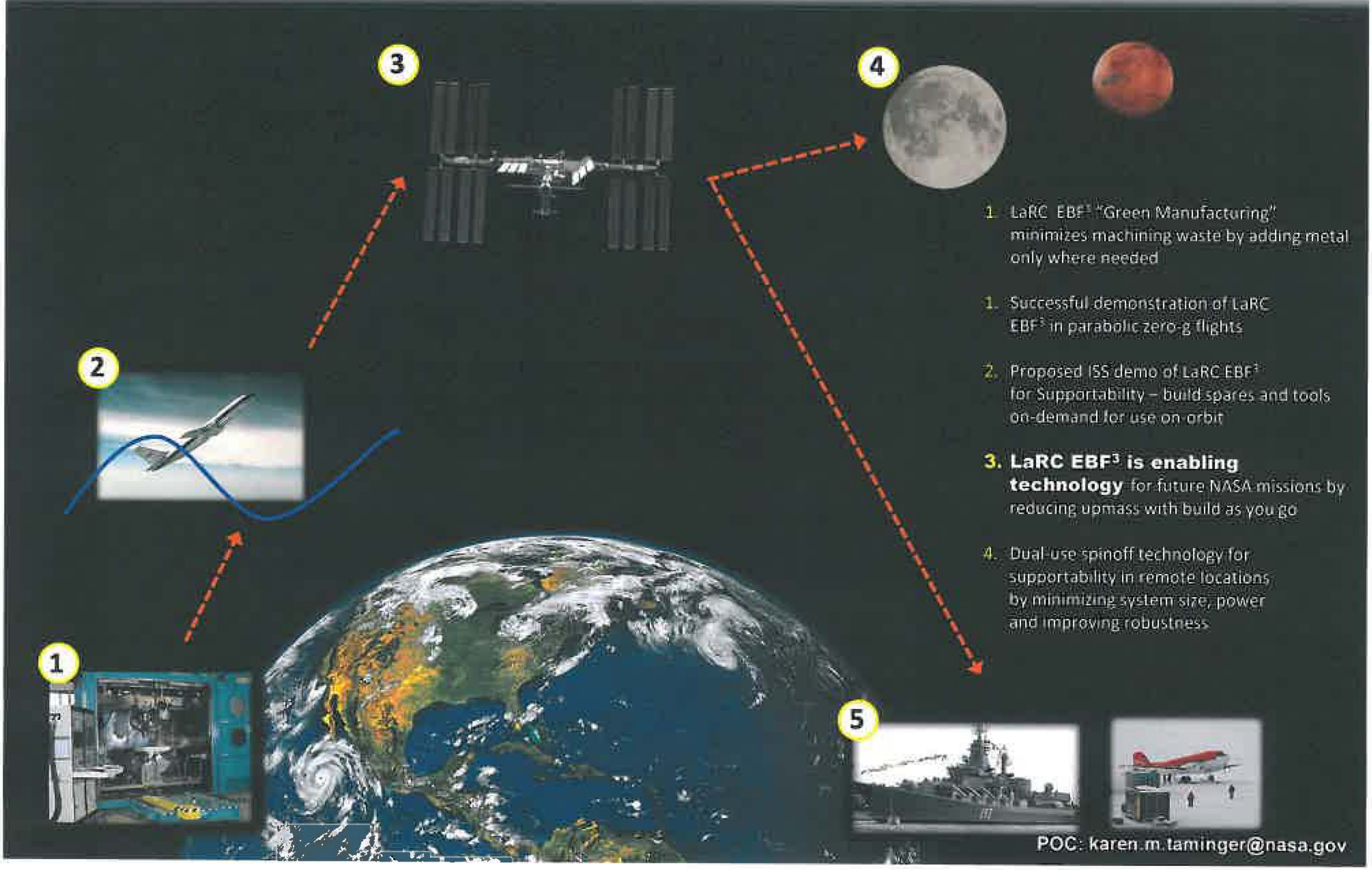
Retire prototype portable system

Next Gen EBF^3 lunar systems build and test

ISS demo of EBF^3 system

Lunar surface system demo

NASA Langley EBF^3 Technology Road Map for Space



1. LaRC EBF^3 "Green Manufacturing" minimizes machining waste by adding metal only where needed

1. Successful demonstration of LaRC EBF^3 in parabolic zero-g flights

2. Proposed ISS demo of LaRC EBF^3 for Supportability – build spares and tools on-demand for use on orbit

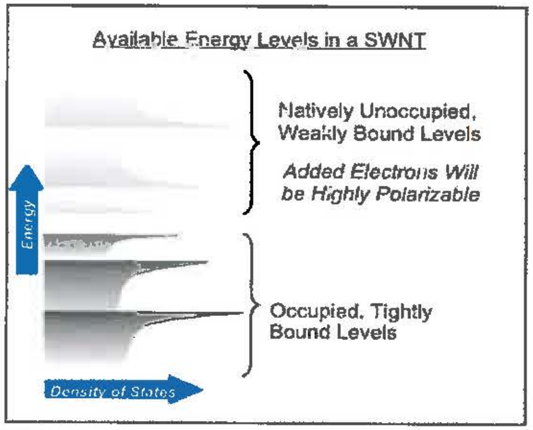
3. **LaRC EBF^3 is enabling technology** for future NASA missions by reducing upmass with build as you go

4. Dual-use spinoff technology for supportability in remote locations by minimizing system size, power and improving robustness

POC: karen.m.taminger@nasa.gov

Coupling Modeling with Experiments to Guide Materials Design

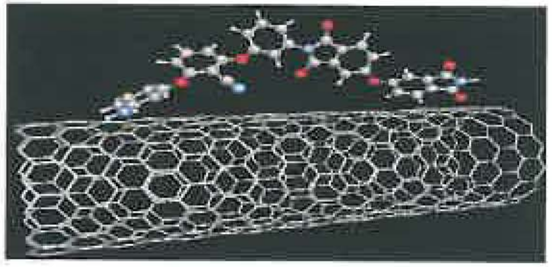
Schematic of Proposed Donor-Acceptor Interactions


Available Energy Levels in a SWNT

Natively Unoccupied, Weakly Bound Levels

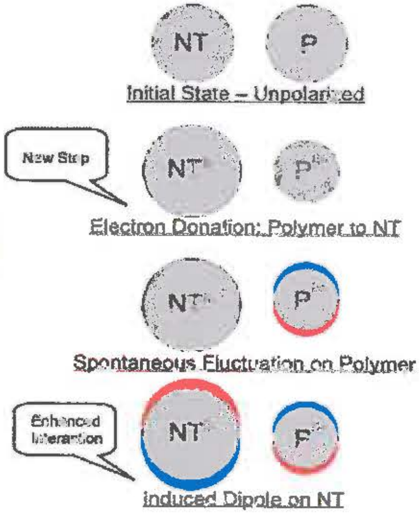
Added Electrons Will be Highly Polarizable

Occupied, Tightly Bound Levels



Quantum Chemical Modeling

Observed Differences in Nanocomposite Solution Stability



Initial State – Unpolarized

New Step

Electron Donation: Polymer to NT

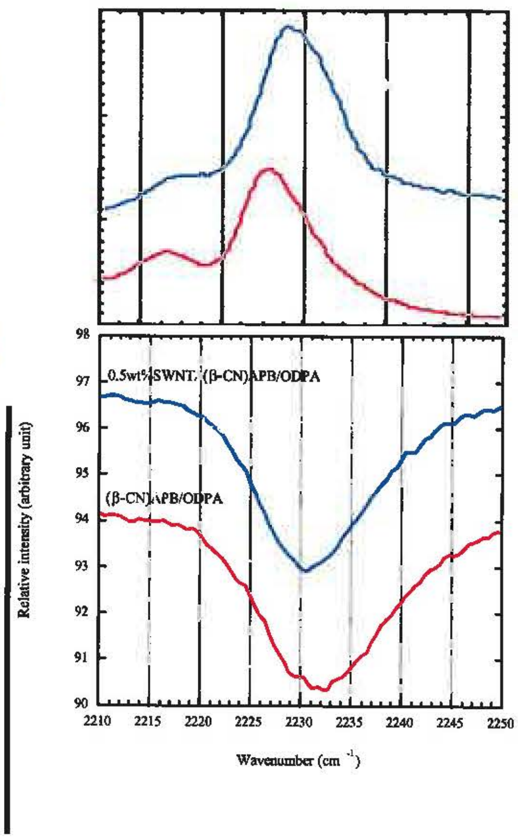
Spontaneous Fluctuation on Polymer

Enhanced Interaction

Induced Dipole on NT

Experimental Evidence of Donor-Acceptor Interactions

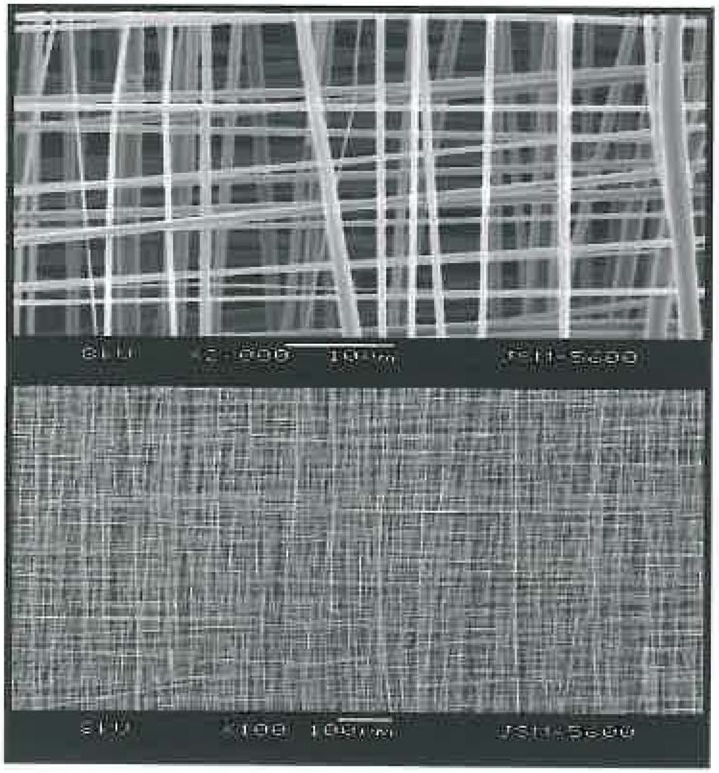
Raman Spectra



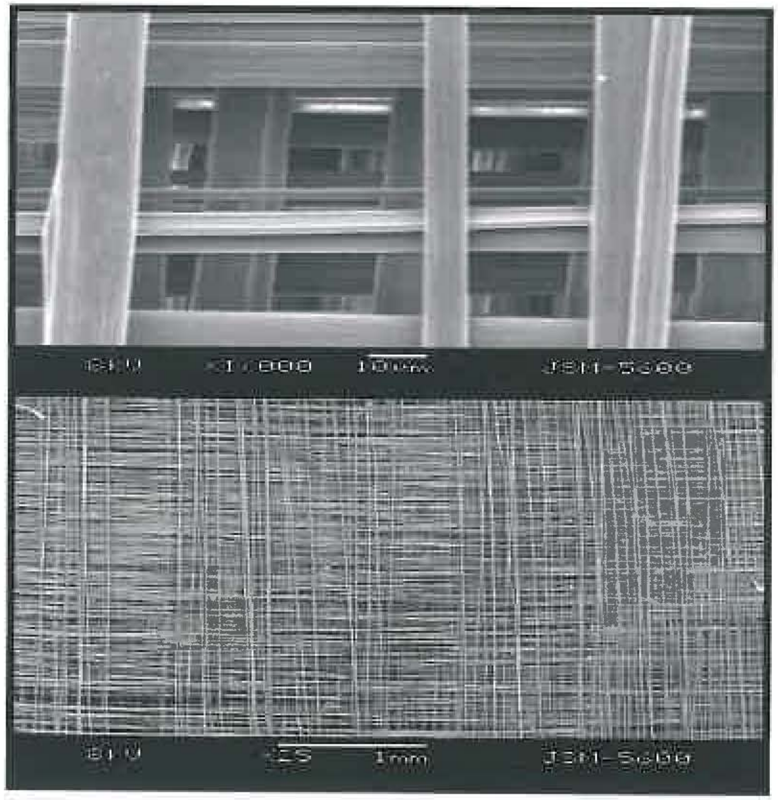
Positioning Ourselves for the Future

Emerging Technologies - Aligned Electrospun Fibers

30 Layer Aligned Mats



PGA 30 Layer mat: top image at 2000x; bottom image at 25x

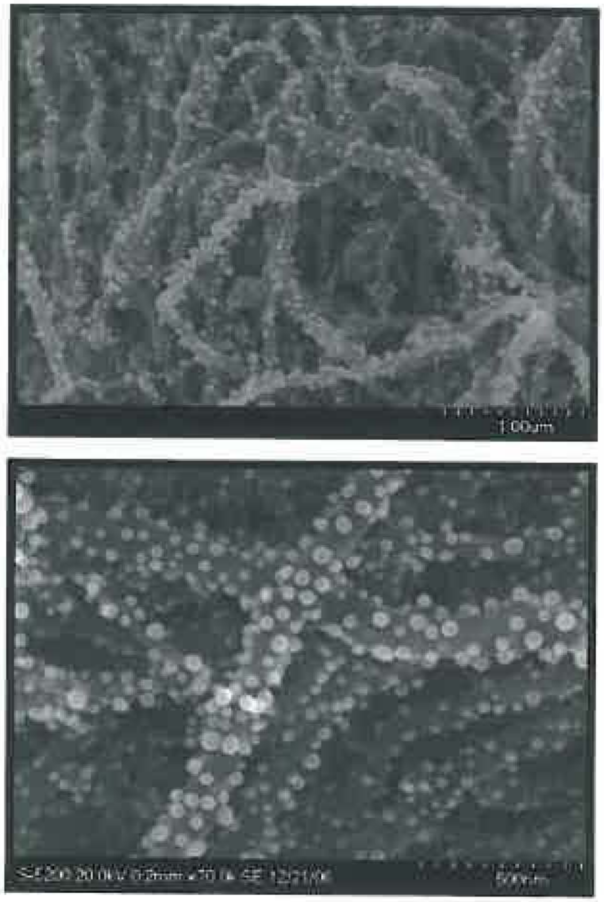


CP2 30 Layer mat: top image at 1000x; bottom image at 100x

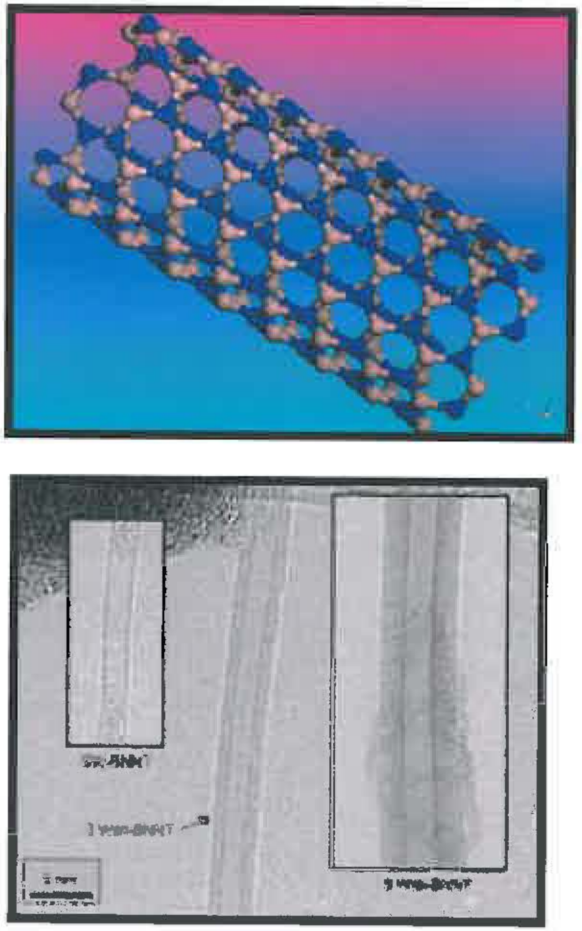
Positioning Ourselves for the Future

Emerging Technologies - Beyond Carbon Nanotubes

Metal Decorated Nanotubes



Boron Nitride Nanotubes

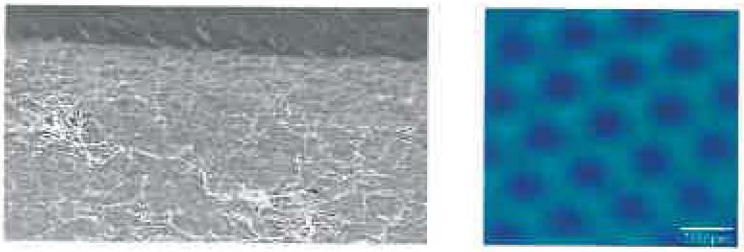


Positioning Ourselves for the Future

Emerging Technologies – NanoTech to Aerospace Materials

Material Synthesis

Cutting Edge Characterization Tools



Custom Processing Capability for Emerging Materials

Computational Modeling

Test Articles for Materials Evaluation

Extruded CNT Nanocomposite

Injection Molded Tensile Test Specimen

Langley Research Center ----
---- from the beginning!

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2017 will be NASA Langley Research Center's 100th Anniversary!

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