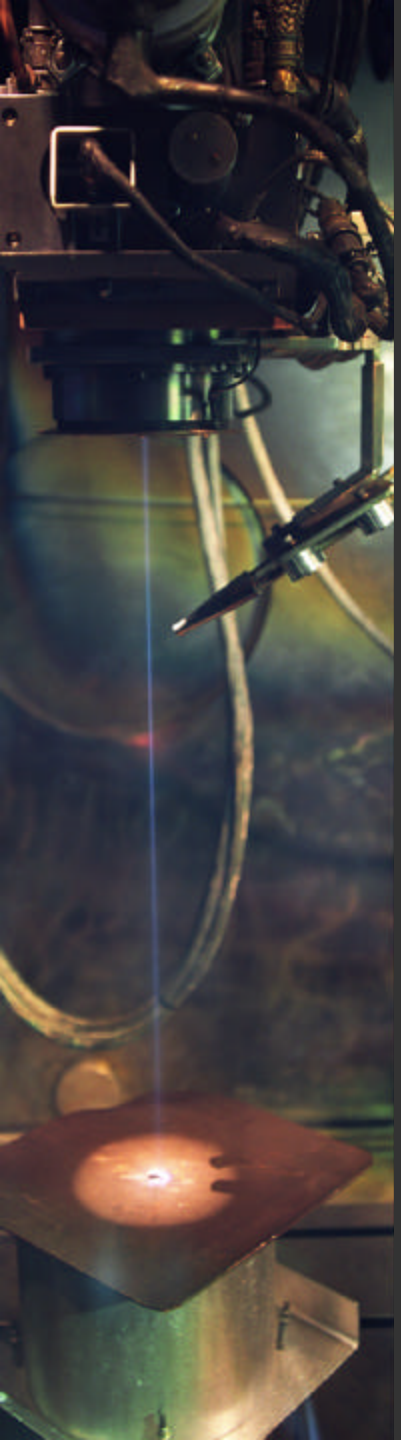

Metals & Thermal Structures Branch
NASA Langley Research Center

Electron Beam Freeform Fabrication Technology Development for Aerospace Applications

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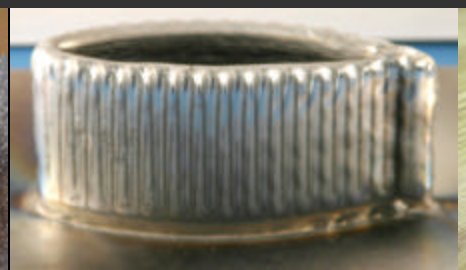
Karen M. Taminger

Airbus Materials & Structures Workshop

April 6-7, 2006

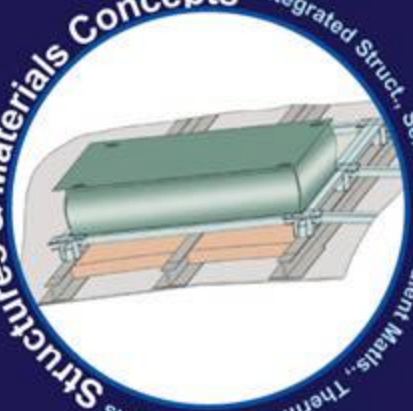



Metals and Thermal Structures Branch

... an integrated structures and materials research organization offering comprehensive conceptual design, analysis and experimentation focused on aerospace applications. Our capabilities include specialized expertise and facilities for processing, characterization and structural testing in extreme environments.

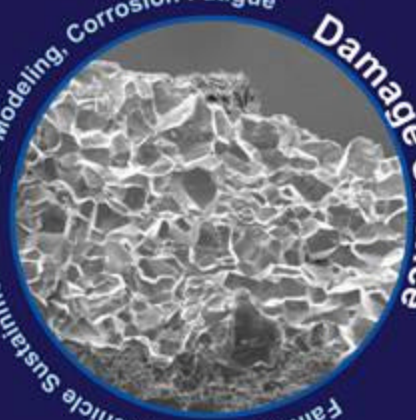
Structures & Materials Concepts

Integrated Struct, Sensory & Gradient Matls., Thermo Mech. Analysis



Damage Science

Fatigue, Corrosion Fatigue, Damage Modeling, Vehicle Sustainment, Failure Analysis



Metals Synthesis & Development

Al, Ti, Ni Alloys, Refractory Materials, MMC's, SMA's, Coatings

Structures for Extreme Environments

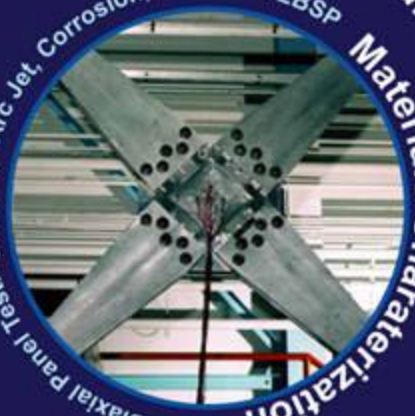
Leading Edges, TPS, Aeroshells, CMC's, Cryotanks

Innovative Metals Processing

EBF3, Process Modeling, RF Plasma Spray, High Energy Ball Mill

Materials Characterization

Biaxial Panel Testing, Mach 5 Arc Jet, Corrosion, SEM/TEM/EBSP



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MTSB Facilities

- Light Alloy Laboratory
- Environmental Fatigue Laboratory
- Biaxial Test Facility
- Advanced Metals Processing Equipment
- Electron Beam Freeform Fabrication Facility
- Metals Cleaning Laboratory
- Hypersonic Materials Environmental Test (HYMETS) Facility
- Thermal Structures Laboratory

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NASA-LaRC Light Alloy Research Facilities

RF Plasma Spray Unit

Metals Processing

- RF Plasma Spraying
- MMC Lay-up
- Cold Isostatic Pressing
- Vacuum Hot Pressing
- Vacuum Induction Melting
- Arc Melting
- Heat Treatment
  - Air up to 3000°F
  - Vacuum up to 2250°F
- Surface Preparation
- Resistance Welding
- E-Beam Free-Form Fab
- Sol Gel Coatings

100 kip Cryo. Test Stand

Mechanical Testing

- Tensile/Compression
  - Loads up to 100,000 lbs
  - -451°F to 2500°F
- Fatigue and Fracture Tests
- Creep
- Biaxial Tension
- Corrosion
- Hypersonic Flow Exposure
- SEM loading stage
  - Loads up to 1000 lbs
  - Temperatures up to 1800°F

Philips 200kV TEM

Metallurgical Analysis

- Optical Metallography
- X-ray Diffraction
  - Residual Stress
  - Texture (ODF)
  - Powder Patterns
- SEM
  - Variable Pressure/Environmental
  - EDS and Microprobe
  - Microtexture
- TEM/STEM
  - EDS
  - EELS/Imaging Filter
- Thermal Analysis
  - DSC (-320°F to 1200°F)
  - DTA & TGA (up to 3000°F)

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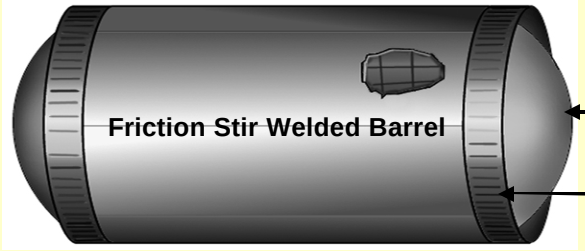
Advanced Manufacturing Methods for Metallic Structure

Processing Improvements

- Demonstrated advanced manufacturing methods to produce metallic structures with increased reliability and safety margins (ALS, NLS programs)
  - Eliminated longitudinal welds via shear forming of single piece 2219 barrel section
  - Integral circumferential stiffeners
- Ongoing collaborative research in friction stir welding (FSW)
  - In-house and SAA funded testing and characterization
  - Industry advisory board chair of NSF Center for Friction Stir Processing
- Combined fabrication methods demonstrated in sub-scale cryogenic tank (CTTP program)
  - Spin forming, roll forging, FSW
  - LaRC / MSFC / Lockheed-Martin collaborative program

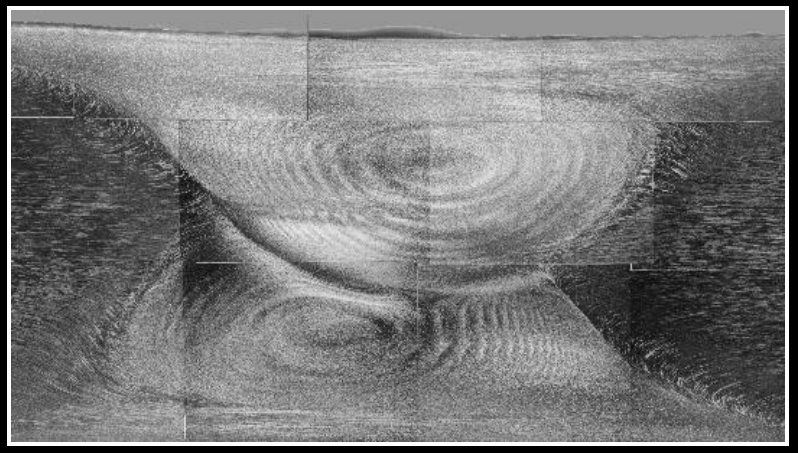
Cryogenic Tank Fabrication Technology Demonstrator



Shear Formed 2219 Al Tank Barrel

- 10' Dia. X 12' Long X 0.25" Thick
- Single piece barrel section
- Employed production tooling used for fabrication of SRB D6AC steel casings

Dual Pass Friction Stir Weld of Al-Li 2195 for Cryogenic Tank Dome Blanks



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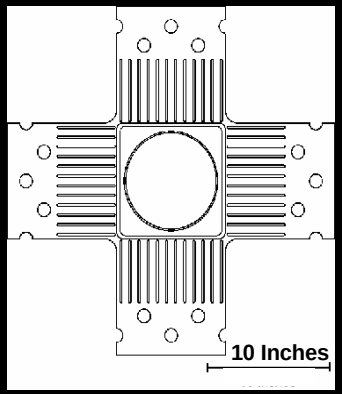
Biaxial Testing Capability at LaRC

Biaxial Test Stand

- 100 kip x 150 kip load capacity
- Room and cryo temperatures

Biaxial Test Specimen

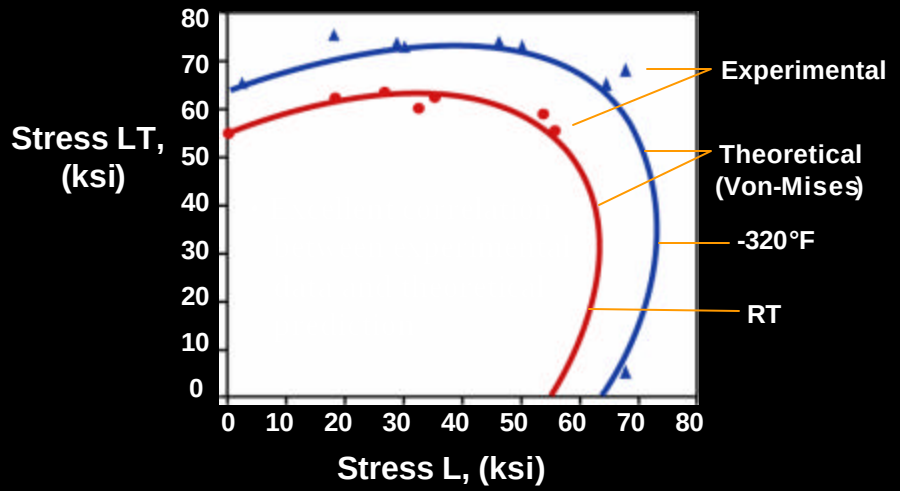


- Biaxial specimen designed at LaRC
- Maximizes region of uniform biaxial stress
- Validated finite element analysis

Biaxial Testing of Al & Al-Li Alloys

- Biaxial yield Locus developed for 2219 & Al-Li 2195
- Yield Locus of 2219 instrumental in redesign of STS external cryogenic tank dome.
- Biaxial tests conducted on conventionally welded and friction stir welded panels.

Yield Locus of 2219-T87 at RT and -320°F



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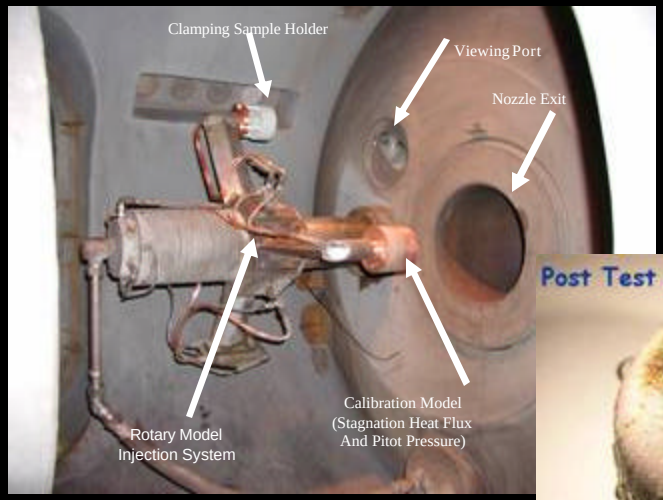
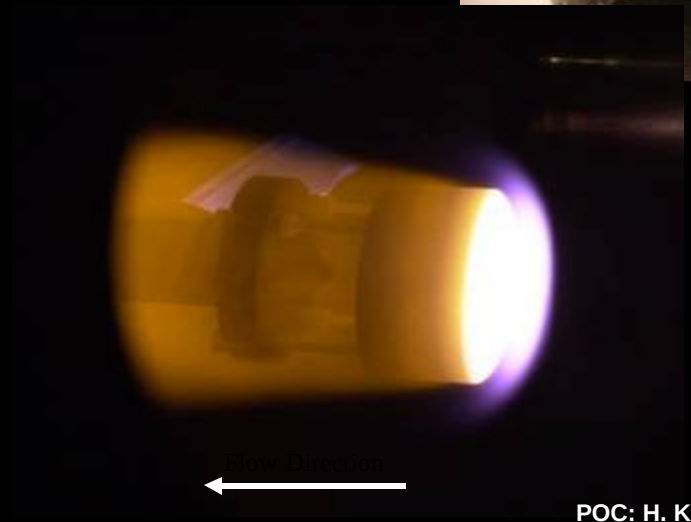
LaRC Hypersonic Materials Environmental Test (HYMETS) Facility

- HyMETS is a small arcjet test facility used to evaluate materials for hypersonic application
  - 1” dia. specimen
  - pressure up to 20 torr
  - enthalpy up to 5500 Btu/lb
  - Cold wall heating rates up to 270 Btu/ft^{2}sec
  - Air Mass flow to 10^{-2} lb/sec

- HyMETS has been used extensively to evaluate materials for use as Shuttle Tile repairs



View inside test cabin



Sample in Flow

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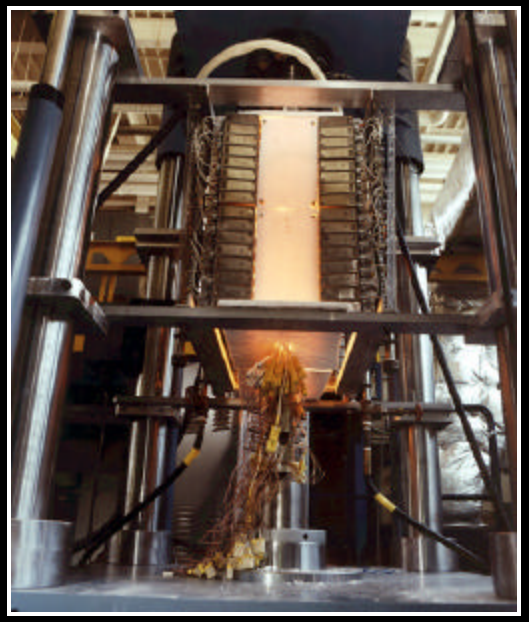
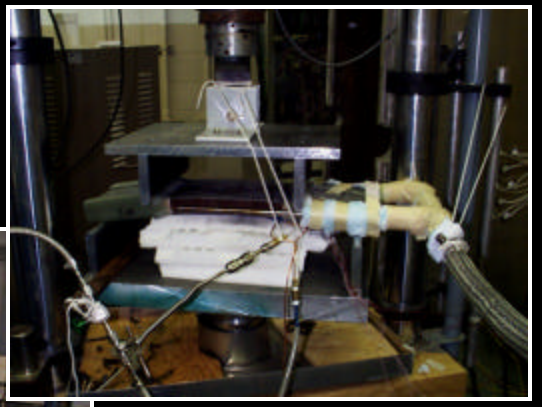
LaRC Thermal Structures Research Facilities

- Focus: Characterize the behavior of advanced thermal structures subject to combined thermal and mechanical loads
- Test systems include seven servo hydraulic test machines ranging from 22k to 500k lbs
- Thermal loads can be applied from -420° F to 2500° F
- Specimens can be tested up to 4 ft x 8 ft
- Custom loading and heating systems are often designed and built for custom tests

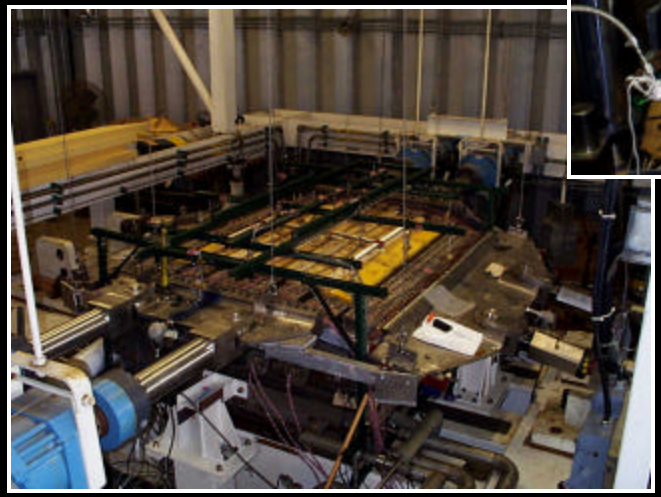


High Temperature Thermal-Mechanical Test

Mechanical Tests of a C/SiC Control Surface Sub-element



LH2 Permeation measurement of a mechanically loaded X-33 tank segment



TPS/tank Integration Tests in the Cryogenic Pressure Box

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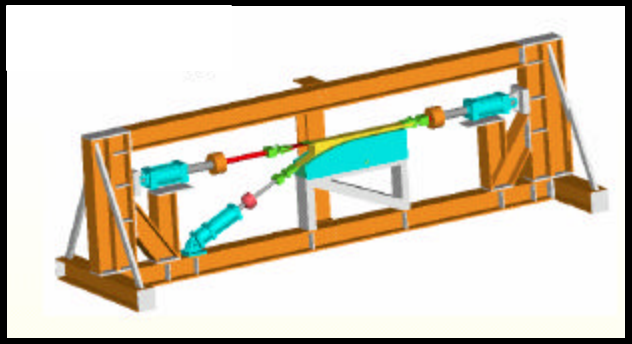
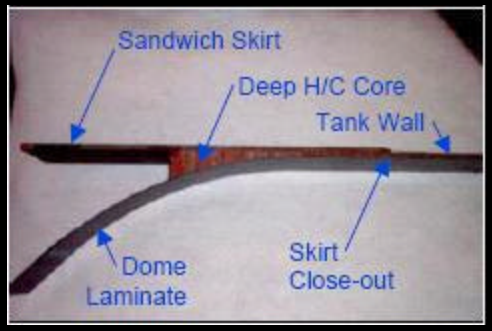
Thermal-Structural Tests of Full-Scale “Y” Joints

- Performed thermal-structural tests of composite cryogenic tank/intertank “Y” Joint structural interface
- Tests performed to -423 °F
- Assessed failure modes and failure loads

Thermal-Structural Test of a Full-scale Cryotank ”Y” joint



CAD model of test apparatus indicating complex loading of test article



Y-joint test article

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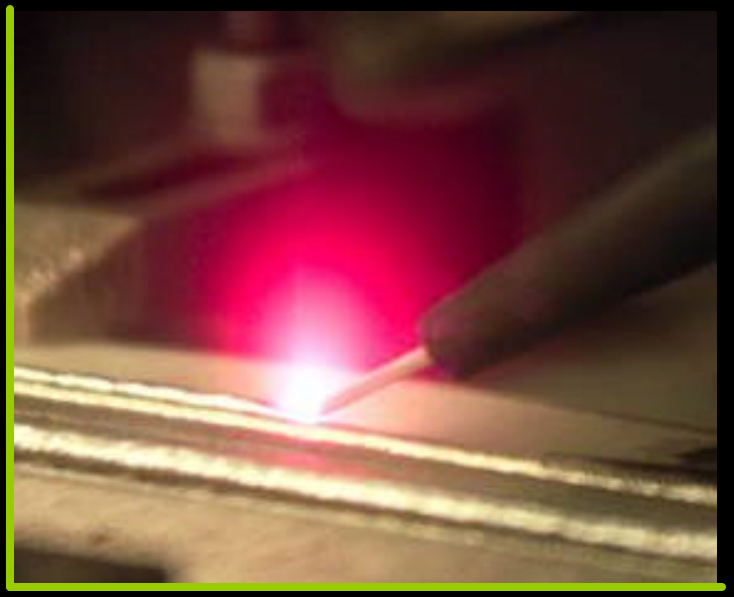
Electron Beam Freeform Fabrication (EBF^3) Process Developed at NASA Langley

Basics

- Layer-additive process to build parts using CNC techniques
- Electron beam melts pool on substrate, metal wire added to build up part
- Material properties similar to those of annealed wrought products
- ~100% dense, structural metallic parts produced directly from CAD file without molds, tooling, or machining
- Secondary processing also possible with reconfigured electron beam
- LaRC has ground-based and portable systems

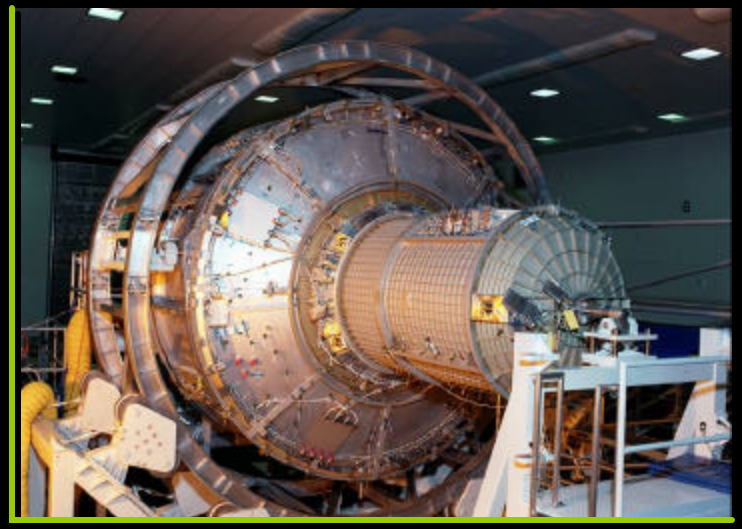


Benefits

- Near-net shape parts minimize scrap & reduces part count
- Efficient design improves weight, assembly time, performance
- Intricate, complex geometries, functionally graded parts & structures
- High energy efficiency and feedstock usage efficiency
- Cross-cutting technology with numerous potential applications

Freeform Fabrication Provides Benefits for Integrally Fabricated Structures

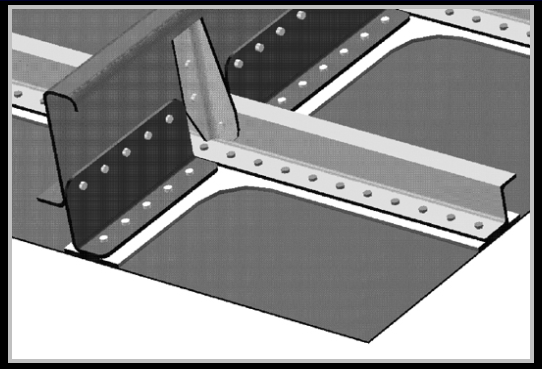
Integrally Machined → Additive Manufactured



- Add features onto simplified casting or forging instead of machining down from oversized billet to leave stiffeners, flanges, bosses, etc.
- Allows design changes later in design cycle
- Significantly reduces starting billet sizes, including costs and lead times associated with handling oversized
- Decreases buy-to-fly ratio and reduces scrap production and handling

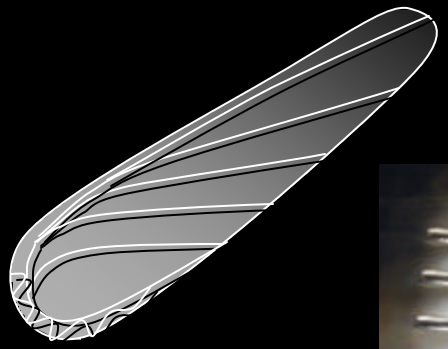
Freeform Fabrication Enables Paradigm Shift to Novel Structural Designs

Designed for Assembly



Assembled from many discrete components

Designed for Performance

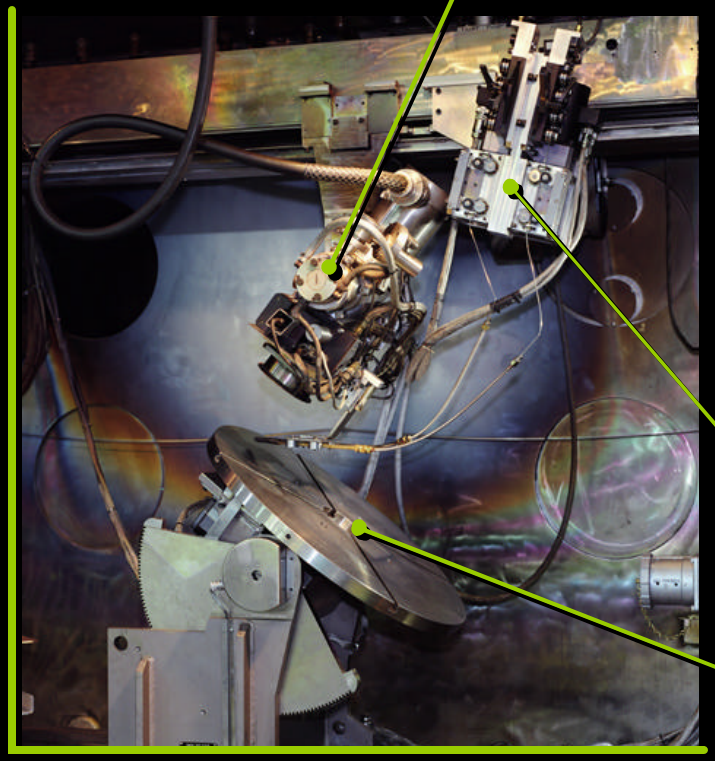


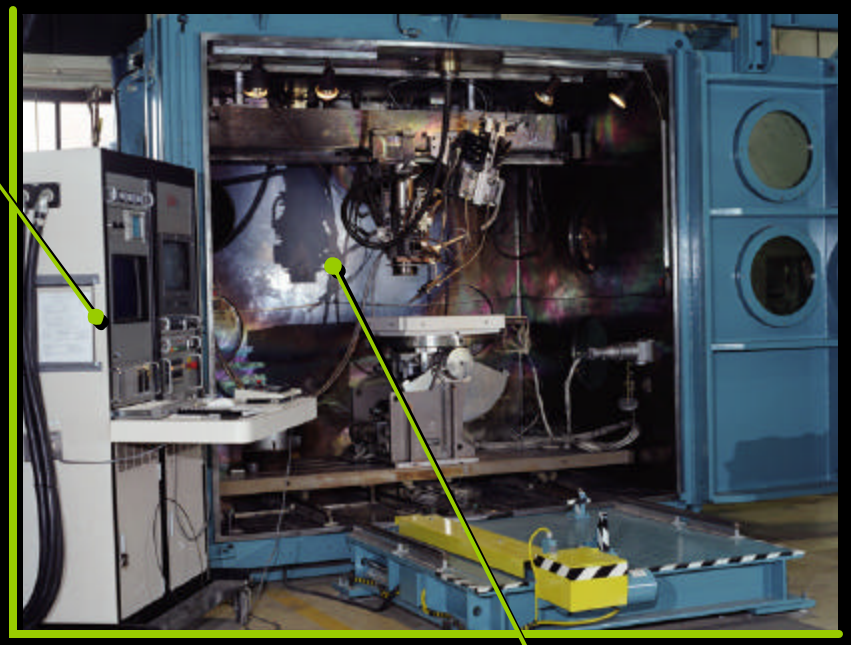
- Freeform fabrication of unitized structure allows use of functionally graded, locally controlled features
- New structural design & analysis tools allow concept development of structures with contoured stiffeners that follow load paths
- New manufacturing process coupled with novel structural analysis and design enables performance enhancements and reduced cost, weight

Comparison of Laser and Electron Beam Deposition Techniques

Laser (Nd:YAG or CO_2)		Electron Beam
5-10%	Wall plug efficiency	95%
Most polymers, ceramics, metals	Materials processed	Electrically conductive materials
Continuous or gated pulsed	Beam control	Continuous or pulsed, programmable raster
Lenses & mirrors or fiber optics (Nd:YAG)	Beam delivery	Magnetically steered
Any (inert gas typical)	Process environment	10^{-5} torr vacuum
Powder	Feedstock form	Wire
5-85%	Feedstock efficiency	100%
0.2 to 4 kg/hr	Maximum deposition rate	> 13.5 kg/hr

Ground-Based EBF^3 System at NASA Langley





Computer Control System

42 kW EB Gun

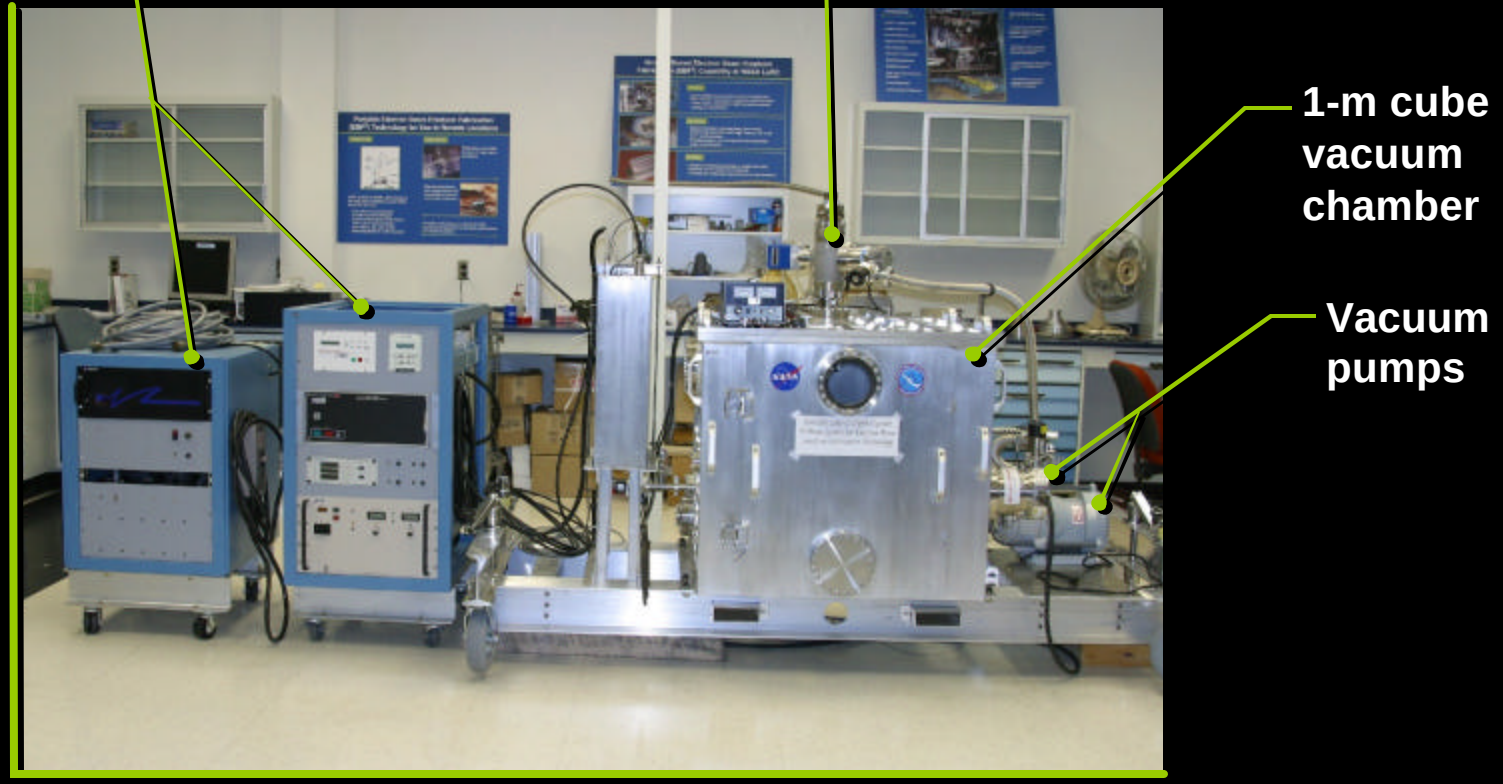
Vacuum Chamber

Dual Wire Feeders

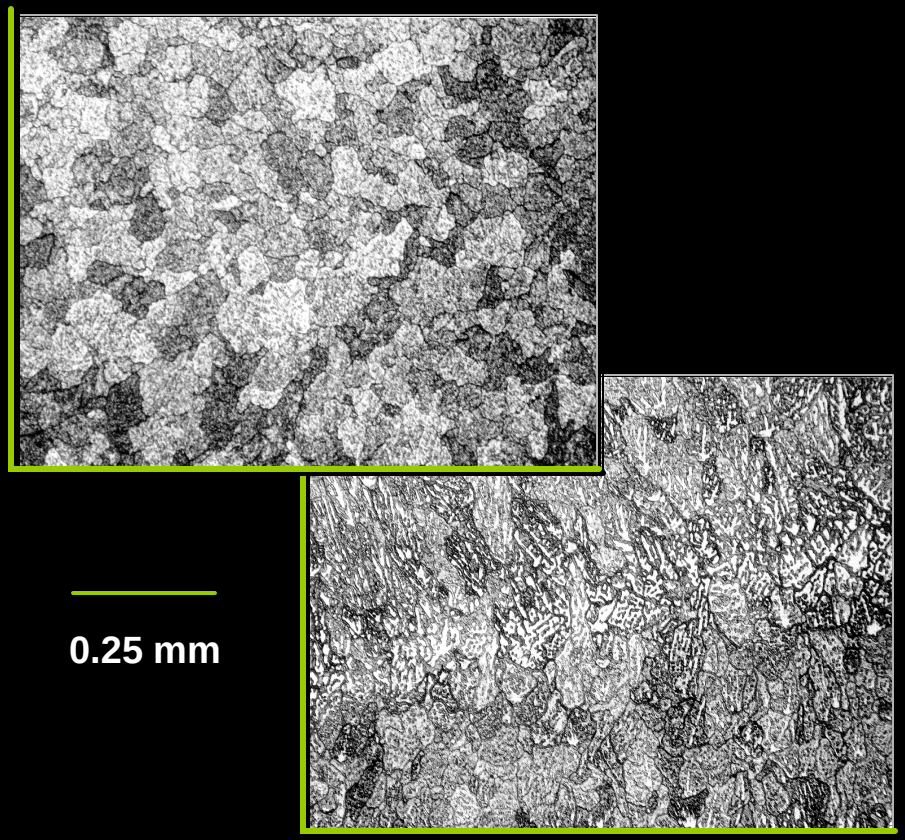
Tilt/Rotate Positioner

EBF^3 Build Demonstration Video

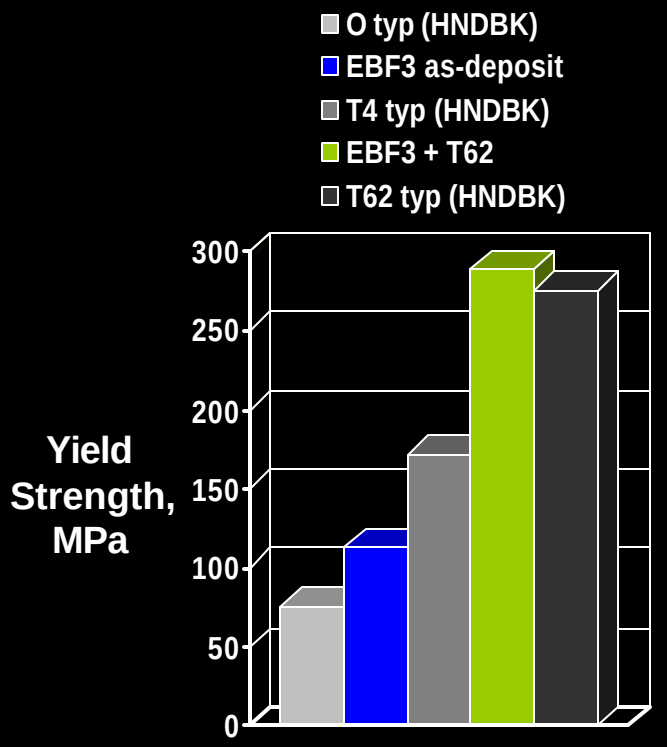
Portable EBF³ System at NASA Langley



2219 Al Produced by EBF^3

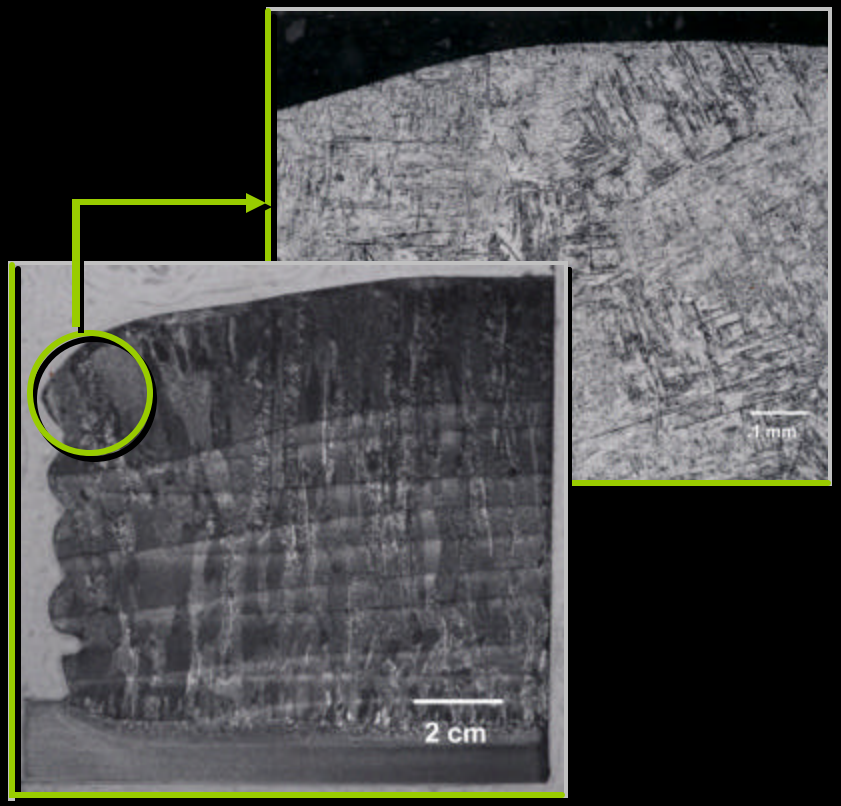


Equiaxed or dendritic grain structure forms depending on processing conditions

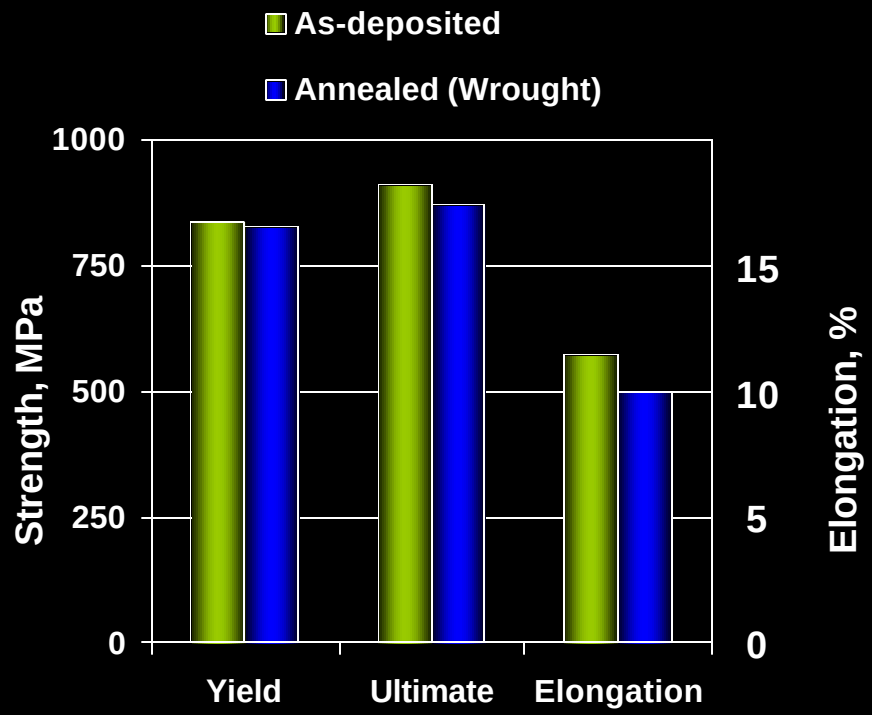


- EBF^3 yield comparable to handbook for T62
- No effect of processing conditions on yield

Ti-6Al-4V Processed by EBF^3

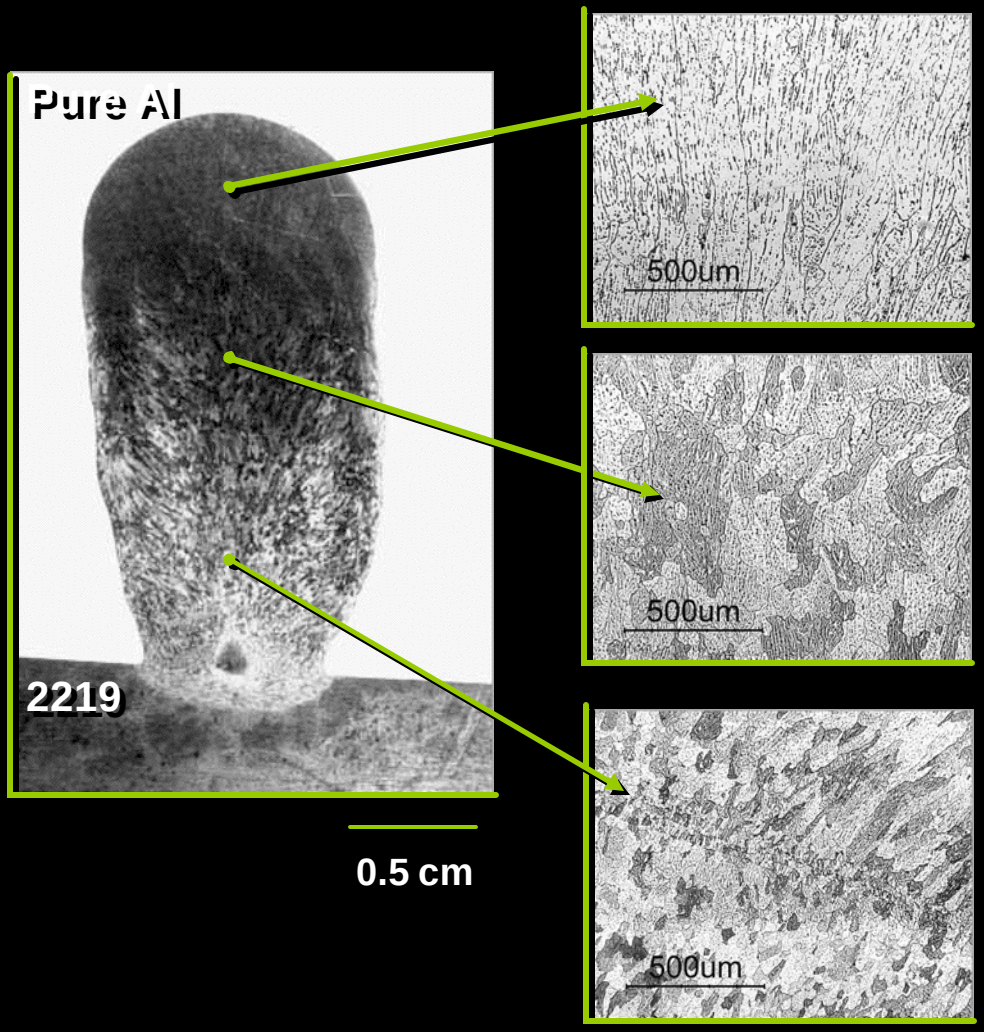


- Large columnar grains grow epitaxially from substrate
- Forms typical alpha-beta lath structure within grains



Properties of EBF^3 deposited Ti-6-4 equivalent to annealed wrought product

Functionally Graded Aluminum Produced by EBF^3



- Transition from 100% 2219 Al to 100% pure Al
- Material combination enables study of mixing and dilution
- Grain morphology varies with composition
- Elemental segregation examined

Summary: Electron Beam Freeform Fabrication

- NASA Langley has developed the EBF^3 process and currently has two EBF^3 systems in-house
- EBF^3 process offers potential cost reduction and fabrication of complex unitized structures out of metals
- EBF^3 has been successfully demonstrated on Al, Al-Li, Ti, and Ni alloys to date

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- Opportunities to collaborate will be dependent upon protection of restricted information