

Advanced Manufacturing Research at NASA Langley



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This presentation provides an overview of capabilities and applications for advanced manufacturing at NASA Langley Research Center

Capabilities include:

- Full suite of commercial off-the-shelf (COTS) additive manufacturing processes
- Specific expertise in Electron Beam Freeform Fabrication (EBF³) for large scale directed energy deposition of metal
- Integration of sensors and computational modeling (process and structural) to support advanced manufacturing
- New capability in forming of single-piece metallic structures

NASA Standard for qualification of AM parts

How to collaborate and partner with NASA Langley

NASA Langley Additive Manufacturing/Rapid Prototyping Capabilities



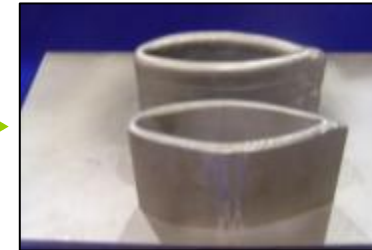
- Stereolithography (SLA)



- Fused Deposition Modeling (FDM)



- Electron Beam Freeform Fabrication (EBF³)



- Selective Laser Melting (SLM) Sinterstation



- Objet Connex



- **Z-Corp - ZPrinter**



- **Makerbot "Thing-O-Matic" 3-D Desktop Printer**



- **Prusa Mendal 3-D Desktop Printer**



- **BotMill - Glider 3-D Desktop Printer**



NASA Langley's Interest in Large-Scale Additive Manufacturing



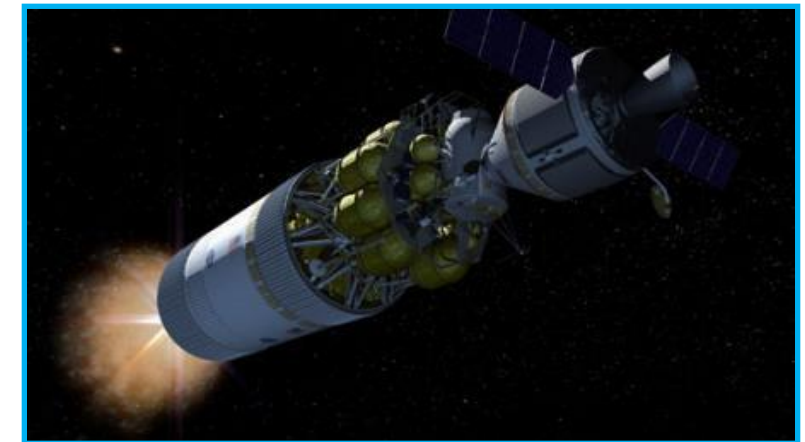
Advanced commercial transport aircraft

NASA space exploration and aeronautics research covers a variety of large-scale vehicles:

- Many are low production volume or prototype vehicles
- Cost of tooling is significant
- Large-scale additive manufacturing and forming processes offer a time and cost benefit

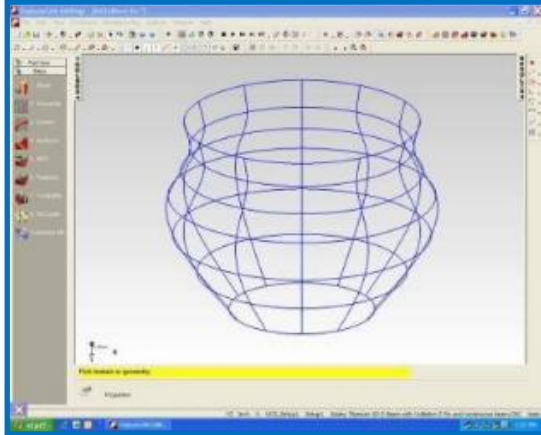


Cryotanks and launch vehicles

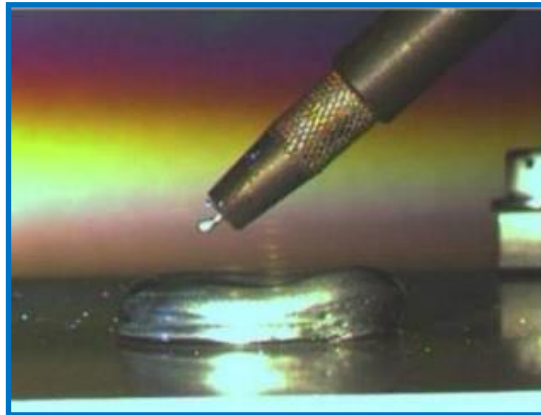


Crew exploration vehicles

Electron Beam Freeform Fabrication (EBF³) Process



Slice CAD drawing



Melt with electron beam, adding wire

- Layer-additive process to build parts using computer numeric controlled (CNC) techniques
- Electron beam melts pool on substrate, metal wire added to build up part
- LaRC has ground-based and portable systems
- Demonstrated on Al, Ti, Ni, Cu and Fe alloys



Build up part, layer-by-layer

EBF³ Process in Action (video)

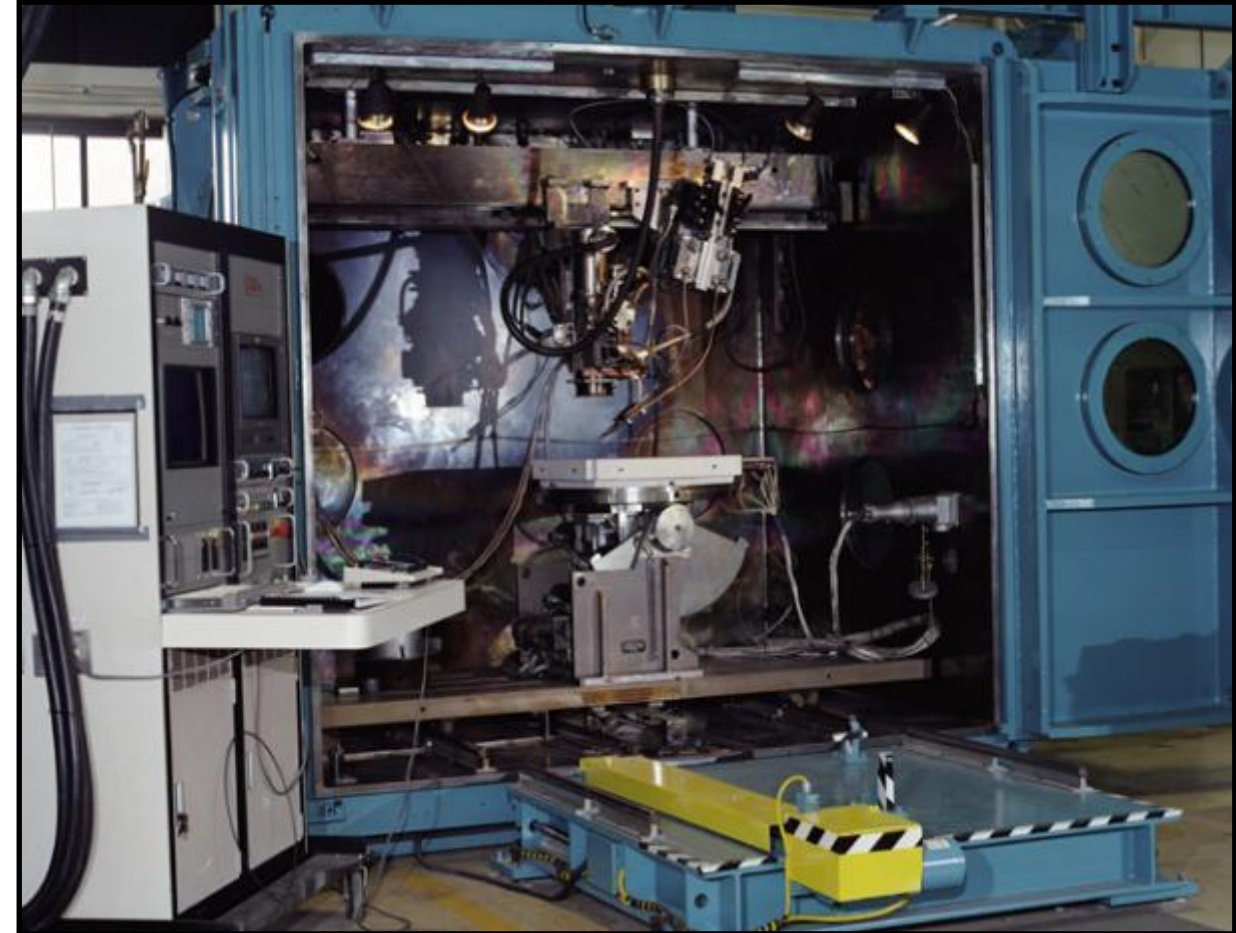
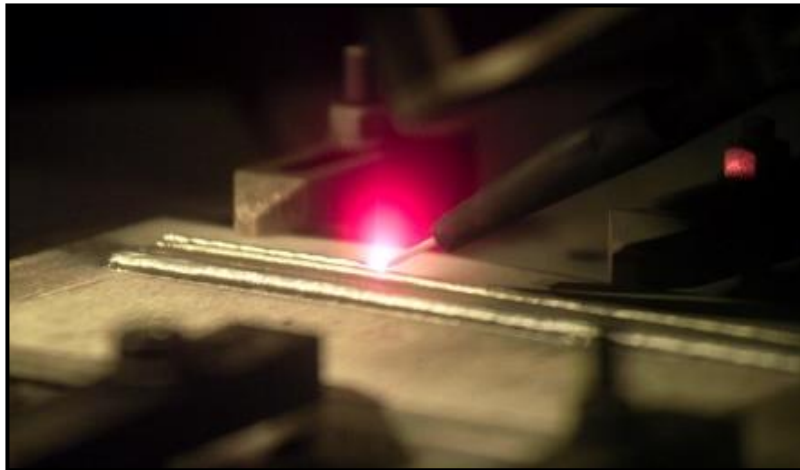


Large-scale EBF³ Capability at NASA Langley

Ground-Based System for Large Structural Components

- Commercial electron beam welder with wire feed and controls added for AM
- Large build volume (72" x 48" x 24") and high deposition rates (3 to 30 lbs/hr). Highest rates possible with lower resolution for parts that will be finish machined
- Dual wire-feed and free-standing, 6-axis part manipulation enables functional gradients and addition of details onto simplified preforms
- System also used for precision electron beam welding

*In-process
EBF³
deposition of
Al-Li alloy*



Large-scale EBF³ system at NASA Langley



As-deposited (Ti-6Al-4V)



Post-machined (Ti-6-4)

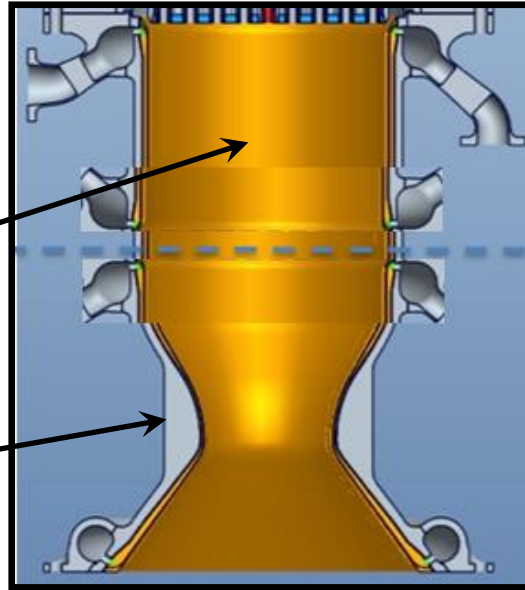
Benefits of Additive Manufacturing (AM) for Rocket Nozzles:

- Rocket nozzles require high temperature, corrosion resistant alloys, such as Ti- and Ni-based alloys (expensive and difficult to machine)
- Nozzle throat difficult to machine from solid billet
- AM significantly reduces machining time and waste
- Wire-fed processes capable of full-scale fabrication and/or cladding of large structures (demonstrated in industry up to 26 feet in diameter)
- Shown: generic nozzle 8 inches in diameter by 18 inches high (Ti-6Al-4V alloy) built using EBF³ and finish machined

Bimetallic Integrated Rocket Combustion Chamber and Nozzle



- Collaboration between NASA's Marshall Space Flight Center, Glenn Research Center, and Langley Research Center
- Cu alloy (GRCop-84) combustion chamber and nozzle produced via Selective Laser Melting (SLM)
- Ni alloy (Inconel® 625) direct deposited onto liner for structural jacket via Electron Beam Freeform Fabrication (EBF³)



Schematic of integrated nozzle

Benefits:

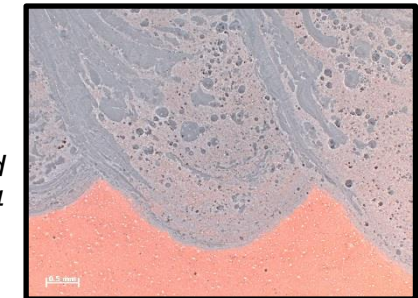
- Reduce manufacturing time from 18 months to < 6 months
- Increased part complexity with cooling passages enabled by additive manufacturing
- Potential to reduce full scale component cost by nearly an order of magnitude (~ 90% reduction)



Selective Laser Melting (SLM) of GRCop-84



Electron Beam Freeform Fabrication (EBF³) of Inconel® 625



Microstructure of EBF³ IN625 direct deposited onto GRCop-84

Small-scale EBF³ Capabilities at NASA Langley

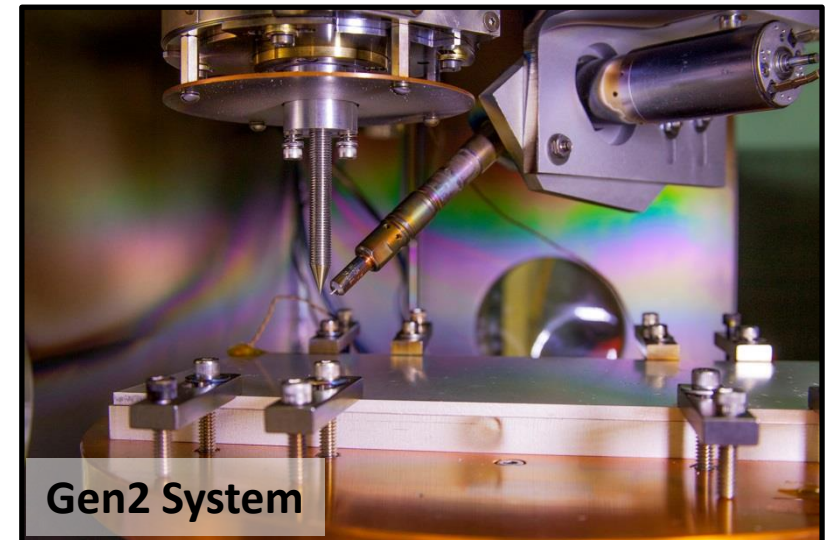


Portable Systems for In-Space Simulation Experiments

- First successful microgravity demonstrations - February 2006
- Microgravity tests support fabrication, assembly and repair of space structures and in-space manufacturing of spare parts
- Smaller build volume (12" x 12" x 12") with finer wire for more precise deposits minimizing or eliminating finish machining
- Two systems designed and integrated in-house to assess different approaches for reducing power, volume and mass without impacting build volume
- Recently received third system (built by COSM under SBIR funding) integrating in-situ electron beam imaging for real time process monitoring and control



Gen1 System



Gen2 System



← *Fine detail builds with smaller scale EBF³ systems*

Deposition during parabolic flight experiments →

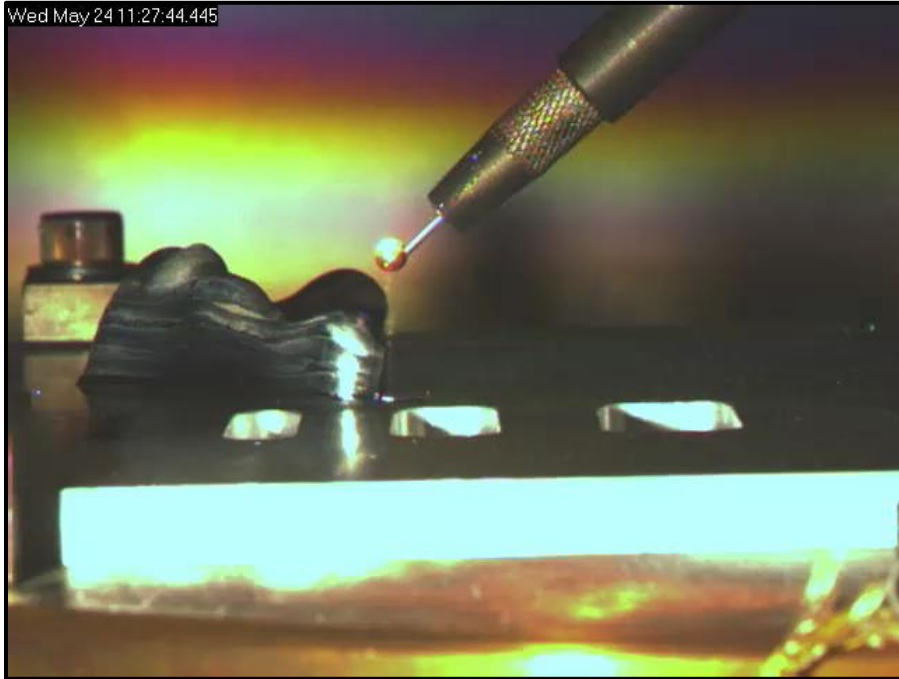


Smaller scale EBF³ systems at NASA Langley

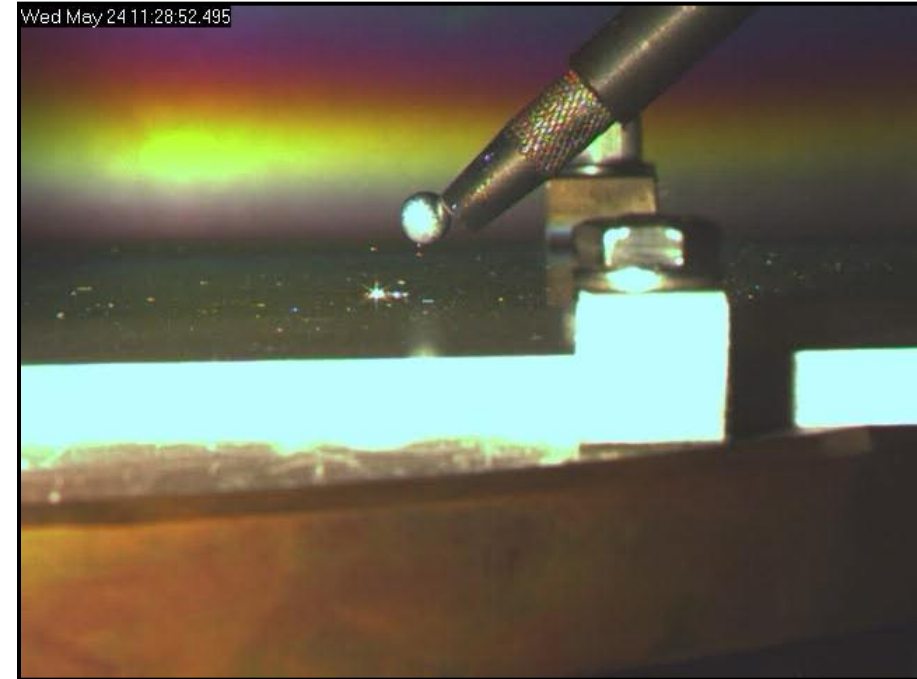
EBF³ Deposition in 0-g (Parabolic Flights)



Incorrect height



Correct height

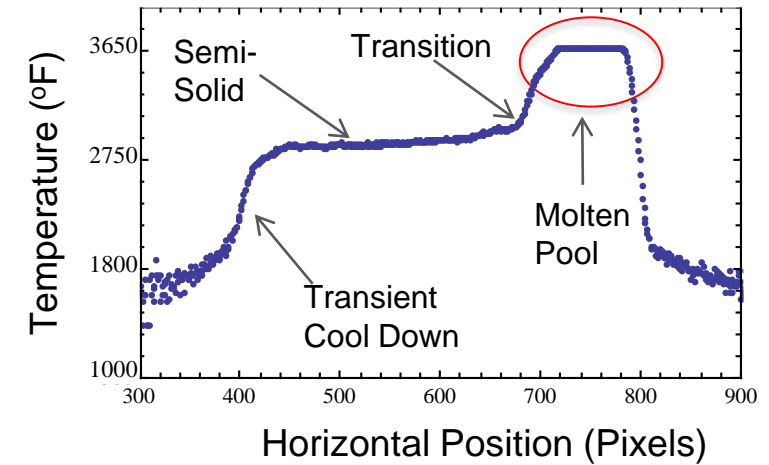
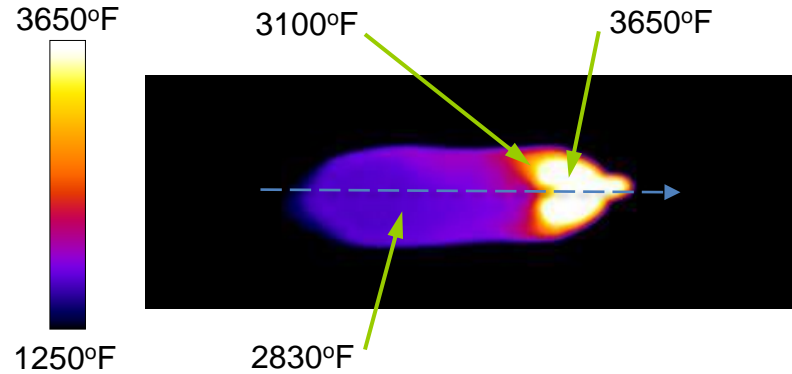


Images of EBF³ deposition of 2219 Al in 0-g portions of parabolic flights

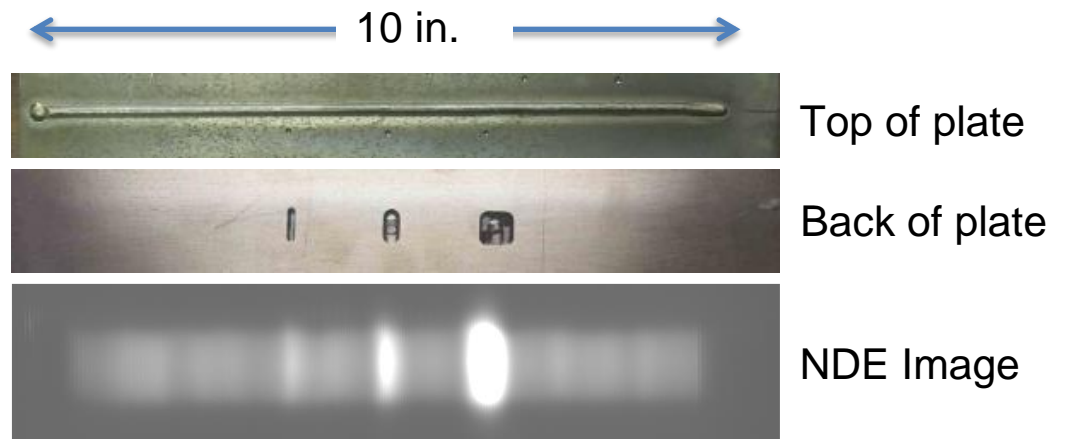
- Attach/detach distances useful for developing build height control
- Maintaining correct distance important to process control in 0-g
- With control, gravity has little effect on EBF³ deposits

Thermal Monitoring During Deposition

Thermal data collected during EBF³ deposition

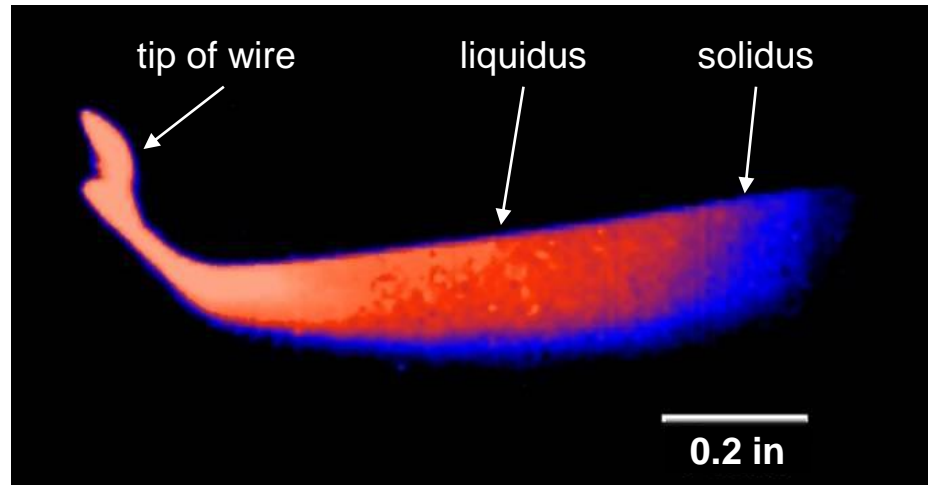


- Thermal imaging using near-infrared cameras provides real-time data during EBF³
- Melt pool region used for process control
- Transient cool-down region used for internal flaw detection
- Valuable for defect detection, process control, and inspection
- NASA Langley has expertise in sensors, data analysis and application to process controls

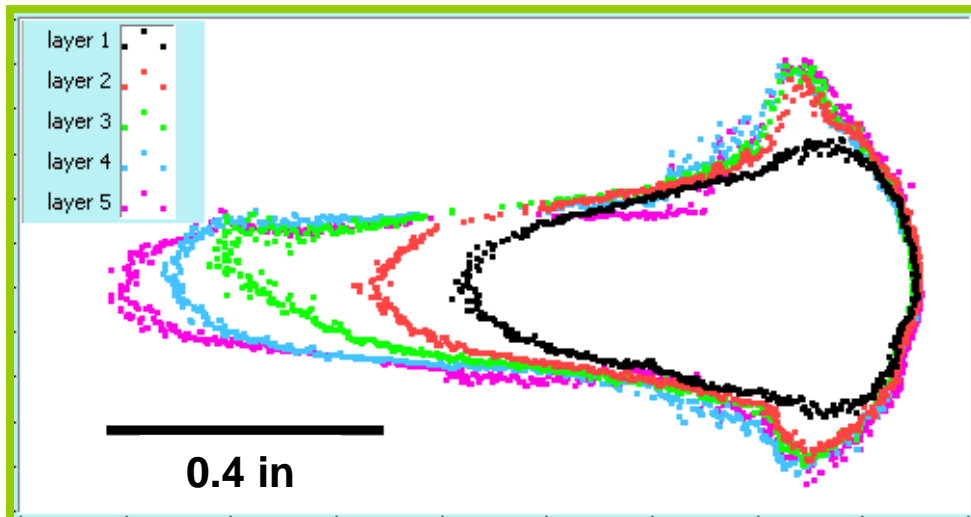


NDE results from single bead experiments

In Process Monitoring and Closed Loop Control Development



Side view of EBF³ process from thermal camera



Melt pool solidus boundary identified from top view thermal camera

Problem:

- Melt pool changes with temperature from one layer to the next during AM

Solution:

- Integrate sensors into AM system for real time imaging of melt pool length, width and depth
- Monitor melt pool size as indication of temperature to implement closed loop process control

Approach:

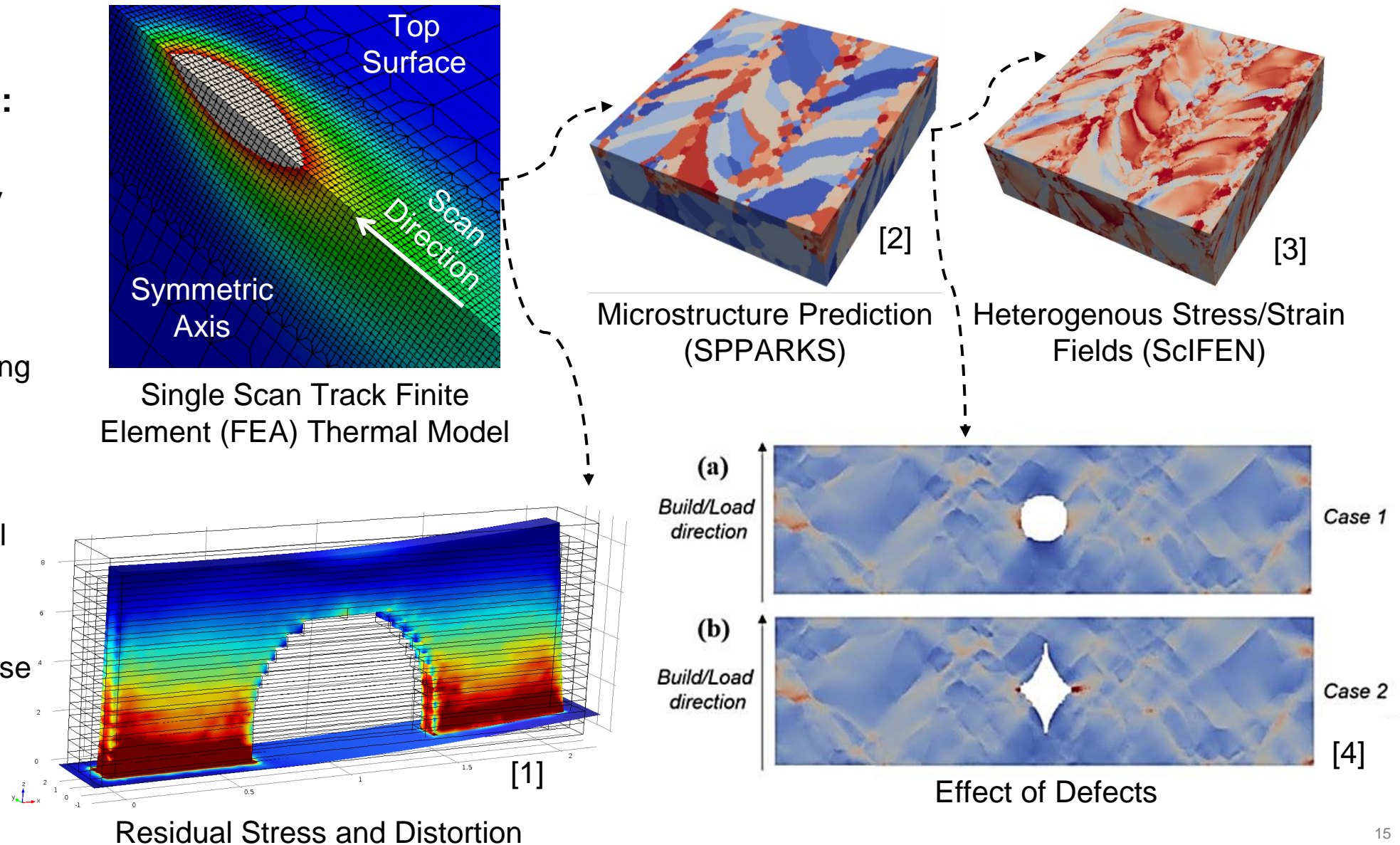
- Integrate sensors into control system
- Refine control logic to correct for other process anomalies (wire irregularities, change in direction)
- NASA Langley has patents awarded for integrated process controls for EBF³

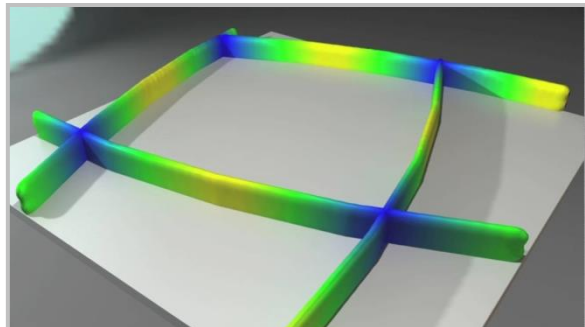
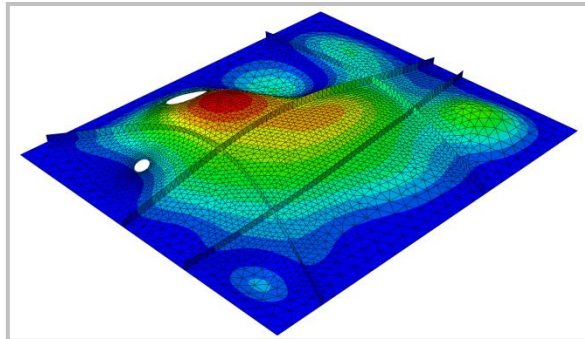
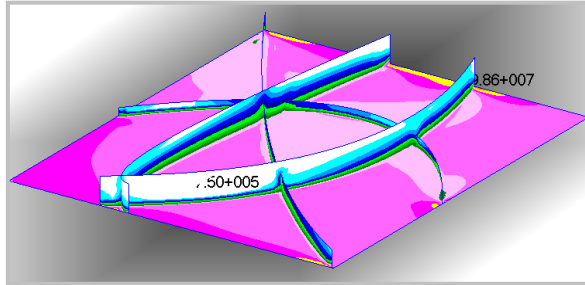
Overview of Modeling Relationships for AM Processes



Process Modeling for Additive Manufacturing:

- Provides insight into process-structure-property relationships and mechanisms
- Implement high-fidelity framework for characterizing property attributes with respect to process parameters and defects
- Accuracy of thermal model affects accuracy of downstream prediction
- NASA Langley has expertise in process modeling and analysis of AM

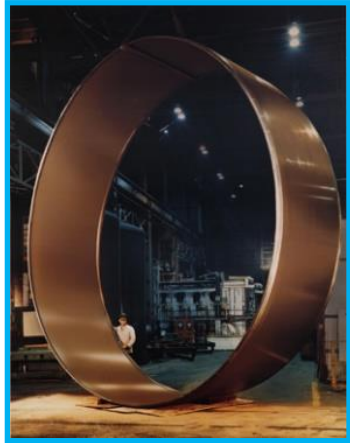




New structural design and analysis tools:

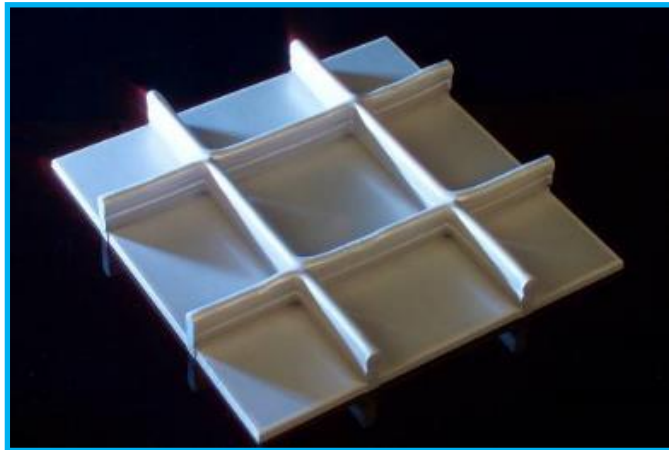
- Optimized for reduced weight and improved performance
- Contoured stiffeners that follow load paths
 - Acoustically-tailored fuselage structures
 - Aeroelastically-tailored wing structures
- Functionally graded stiffeners for material properties customized to structural needs
- Selectively reinforced structures for improved stiffness and damage tolerance
- Design tools integrated with established analysis codes being developed at NASA Langley and VA Tech

Combined Manufacturing Processes for Large Aerostructures

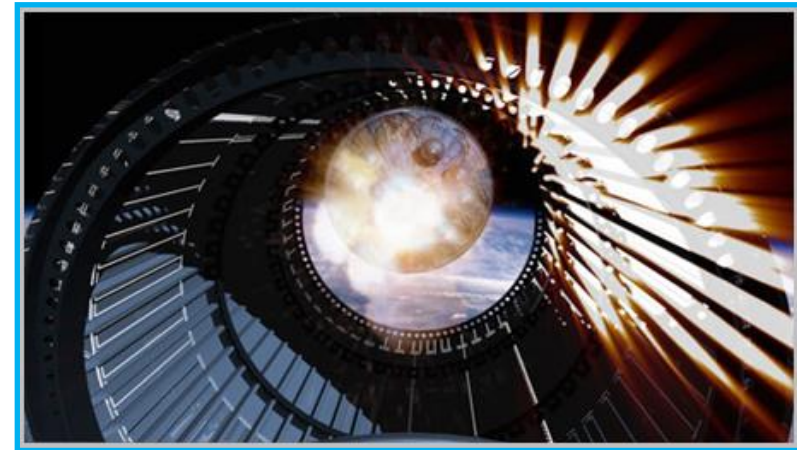


Flow-formed cylinder

- Form single-piece cylinder (extrude, shear or flow form)
- Deposit integral stiffeners to stiffen walls
- Enables tailored stiffener arrays and unitized fabrication, eliminating weight and flaws at joints
- Potential application for cryotanks, launch vehicles and fuselage structures



Deposit internal structural stiffeners

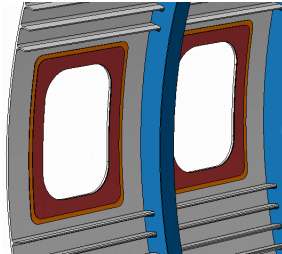


Goal = integrated structure without fasteners

Lightweight Metallic Fuselage Manufacturing Demonstration



Window upper/lower transoms and floating window frames



2) Window areas machined (MSFC)



1) ISC formed barrel (MT Aerospace)



Flow-formed integrally stiffened skin and stringer fuselage

Stretch-formed Z-ring frames and shear clips



3) Ring frames RFSSW installation (Lincoln Electric Automation)

4) Floor beams riveted installation (LaRC)



Brake-formed C-channel floor beams

5) Floor panels bolted installation (LaRC)

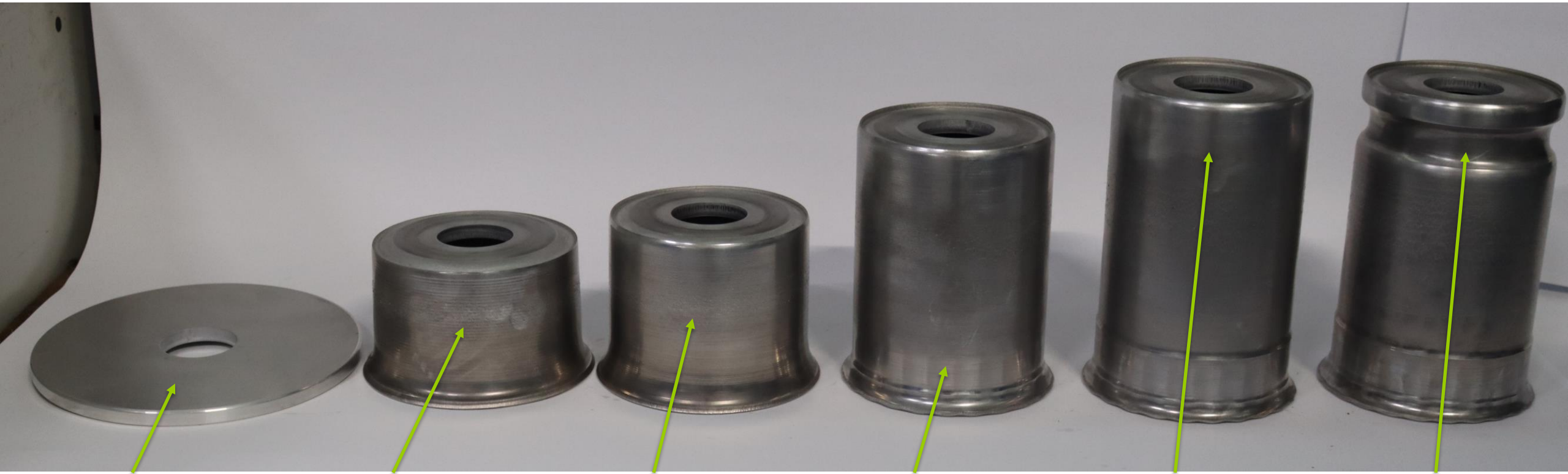


Extruded J-stiffened floors

Demonstrated forming and assembly techniques reduce manufacturing time by 50%, cost by 2-3%, and weight by >9%

New In-House Forming Capability at NASA Langley

- “Stock” forming mandrel demonstrates 5 different forming operations possible with VUD-600
- 90% thickness reduction and change in shape accomplished in < 2.5 min. at room temperature



Forming blank

- 8” diameter flat plate
- Different mandrel required to start with cylindrical preform

Spin/shear forming

- Shapes forming blank over mandrel
- No change in wall thickness

Forward flow forming

- Increases length of cylinder while reducing wall thickness
- Cylinder grows in same direction as roller movement

Stiffener fabrication

- Continuation of forward flow forming
- Forms stiffeners on inner mold line into grooves on mandrel

Back flow forming

- Increases length of cylinder and reduces wall thickness
- Cylinder grows in opposite direction of roller movement

Neck-in/hub forming

- Reduces diameter of cylinder after back flow forming off top of mandrel

NASA Standard 6030 – Additive Manufacturing Requirements for Spaceflight Systems



Standard (released April 2021) covers:

- Part classification (higher risk/impact carries more stringent requirements)
- Process controls and documentation ensure repeatability and traceability
- Requires thorough understanding of process parameters from feedstock storage and handling through post-deposition processing
- Configuration controls on AM hardware and software
- Statistical process control based on pre-production mechanical property testing and witness coupons in production builds
- Provisions start with part-specific qualification (not qualification of AM process for any part)
- Current focus is laser powder bed fusion (LPBF)
- Future plans will update standard to expand to directed energy deposition (need to address closed loop controls that adapt process parameters to real time build conditions)

Questions?

For more information on partnering with NASA Langley, please contact:
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