NASA TA-12 Roadmap Review: Manufacturing and Cross Cutting

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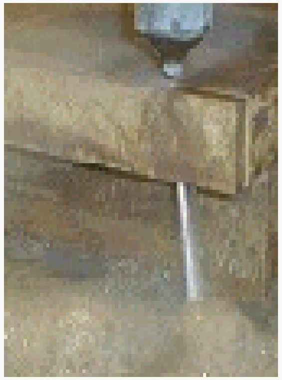
Biosketch of Ming Leu

- **Employment History**
  - Director, Center for Aerospace Manufacturing Technologies, 5/04-present
  - Director, Intelligent Systems Center, 10/03-present
  - Keith and Pat Bailey Distinguished Professor in Integrated Product Development, Missouri S&T, 1999-present
  - Program Director for Manufacturing Machines and Equipment, National Science Foundation, 1996-1999
  - State Chair Professor in Manufacturing Productivity, New Jersey Institute of Technology, 1987-1996
  - Assistant Professor in Mechanical Engineering, Cornell University, 1981-1987
- **Education**
  - Ph.D. in Mech. Eng. (1981), University of California at Berkeley
  - M.S. in Mech. Eng. (1977), Pennsylvania State University
  - B.S. in Mech. Eng. (1972), National Taiwan University
- **Research Interests**
  - CAD/CAM, virtual prototyping, freeform fabrication
- **Research Records**
  - ~300 papers in journals and conference proceedings, 8 book chapters, 4 patents
  - Principal advisor of 23Ph.D. & over 60 M.S. graduates and 15 post-docs

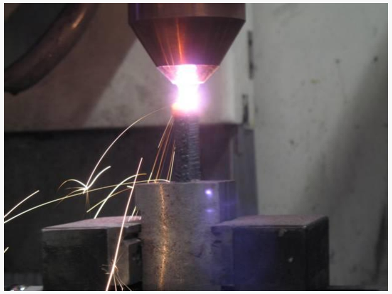
The Center for Aerospace Manufacturing Technology (CAMT) Research Areas

Composites Fabrication and Evaluation

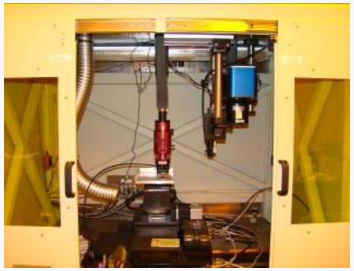
Titanium Machining



Abrasive Slurry Cutting



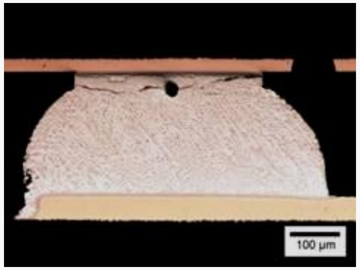
Rapid Prototyping & Manufacturing



Laser Materials Processing

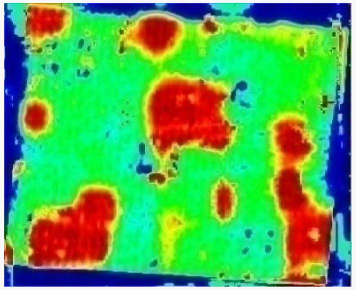
Assembly Modeling & Simulation

Friction Stir Processing



Lead-Free Soldering

Non-Chrome Coating



Non-Destructive Evaluation

Present Members of CAMT Industrial Consortium

Gold Member ($200,000 Annual Fee)

BOEING®

Full Member ($50,000 Annual Fee)

GKN AEROSPACE

SPIRIT AEROSYSTEMS™

Bell Helicopter
A Textron Company

ROLLS ROYCE Rolls-Royce

SIEMENS

KMT

Pie
Product Innovation & Engineering, LLC

Assoc. Member ($15,000 Annual Fee)

Steelville Manufacturing Co.

NASA Portfolio in Manufacturing and Cross Cutting

- **Manufacturing**
  - Manufacturing Processes
  - Intelligent Integrated Manufacturing and Cyber Physical Systems
  - Electronics and Optics Manufacturing Processes
  - Sustainable Manufacturing

- **Cross Cutting**
  - Nondestructive Evaluation (NDE) and Sensors
  - Model-based Certification and Sustainment Methods
  - Loads and Environments

Manufacturing Process

a. Metallic Processes

b. PMC & MMC Processes

c. CMC Processes

d. In-Space Assembly, Fabrication and Repair

e. Smart Materials Production

f. Multi-scale Modeling and Simulation

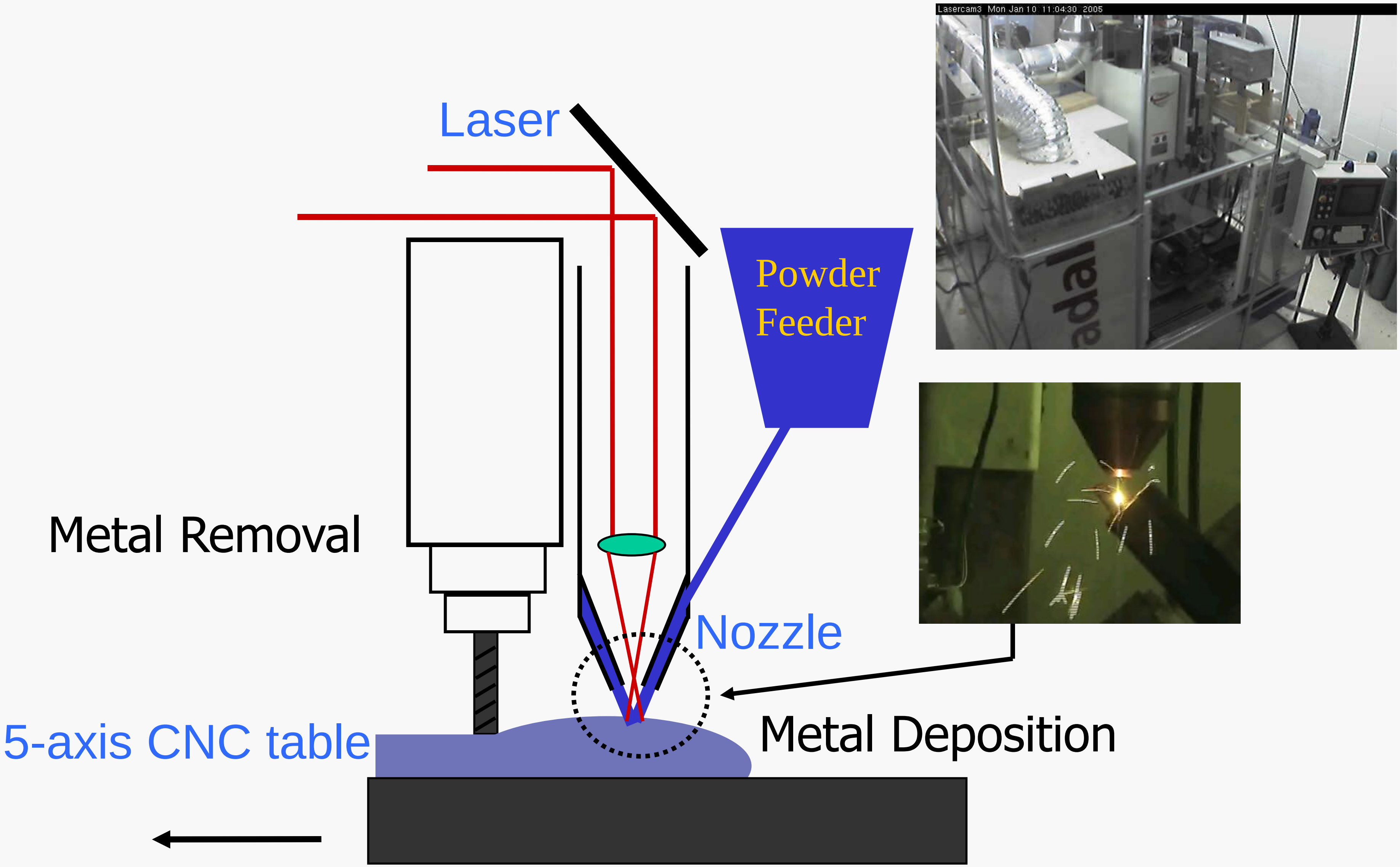
g. Nanomanfuacturing

Comments on Manufacturing Process

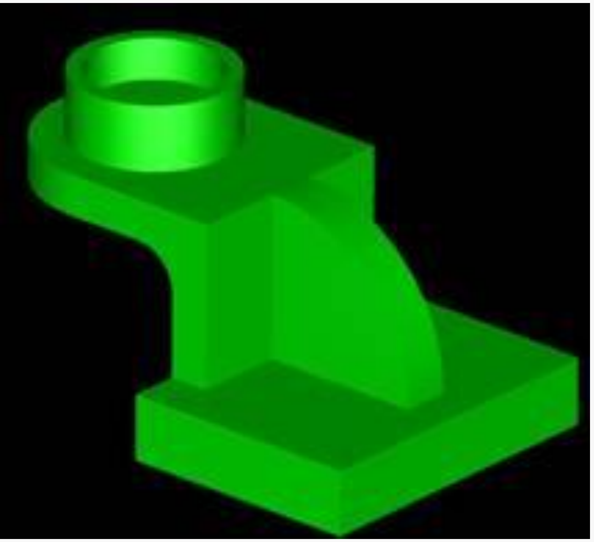
- The listed five topics are all fine, but I suggest adding two more as described below.
- Multi-scale modeling interfaces and integrates formulation of mathematical models from atomic scale to continuum scale. Multi-scale modeling and simulation will be critical to understanding of manufacturing processes for all kinds of composites (PMC, MMC and CMC). I suggest to include “Multi-scale Modeling and Simulation” for long-term research.
- Nanomanufacturing is extremely promising and is expected to be a game changer for manufacturing. Nanomanufacturing potentially has many applications, such as making products much stronger and much lighter, thus I suggest to include it for long-term research. To be more fruitful, NASA can leverage on the research work of the four nanomanufactruring focused research centers currently funded by NSF.

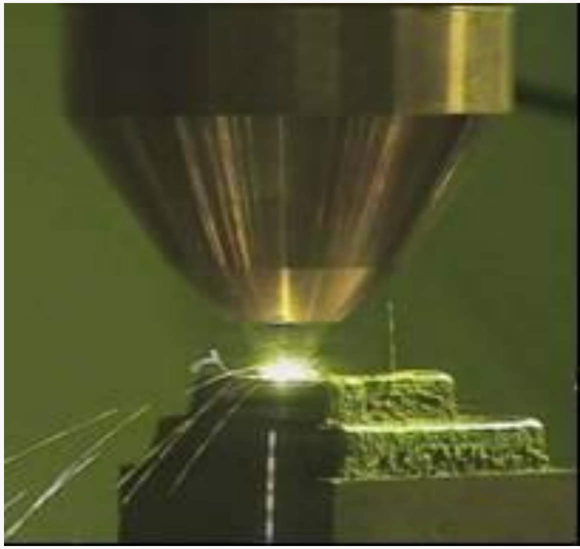
Laser Assisted Material Processing (LAMP)

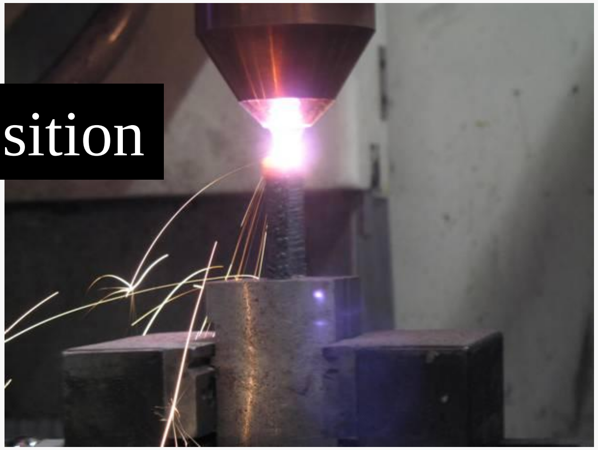
- A Hybrid Deposition and Removal Process -



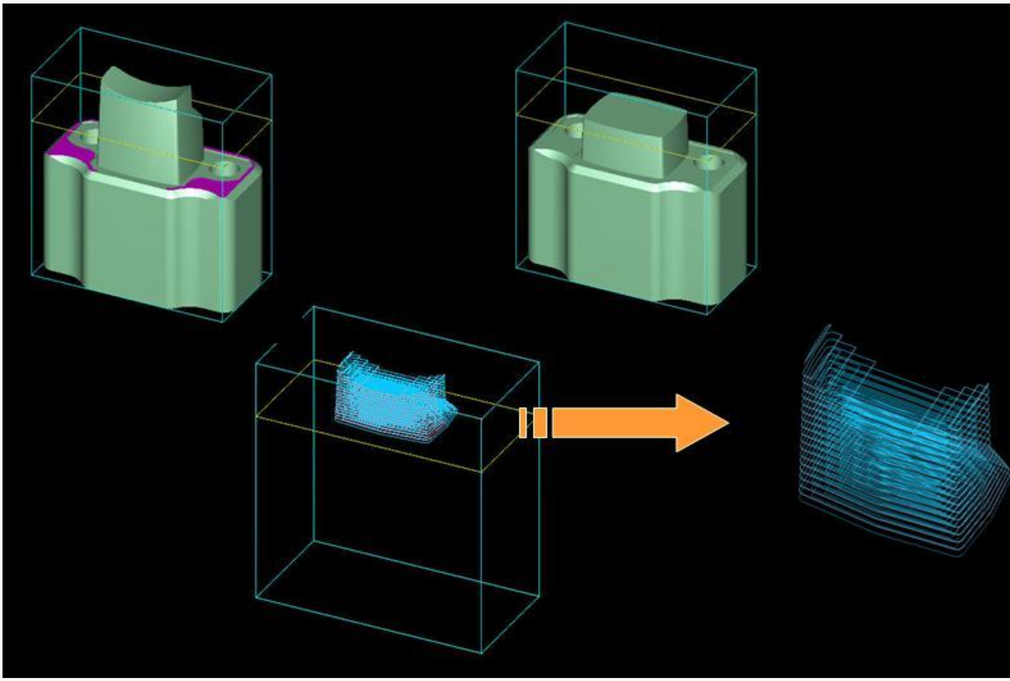
3-D Part Building: Bearing Part and Turbine Blade

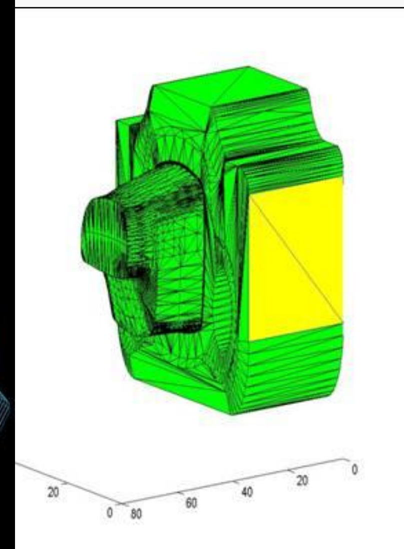




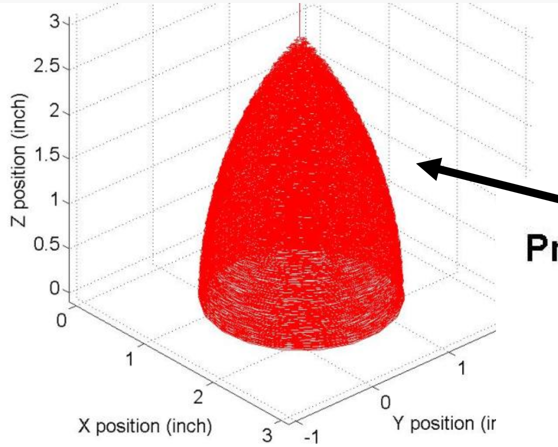


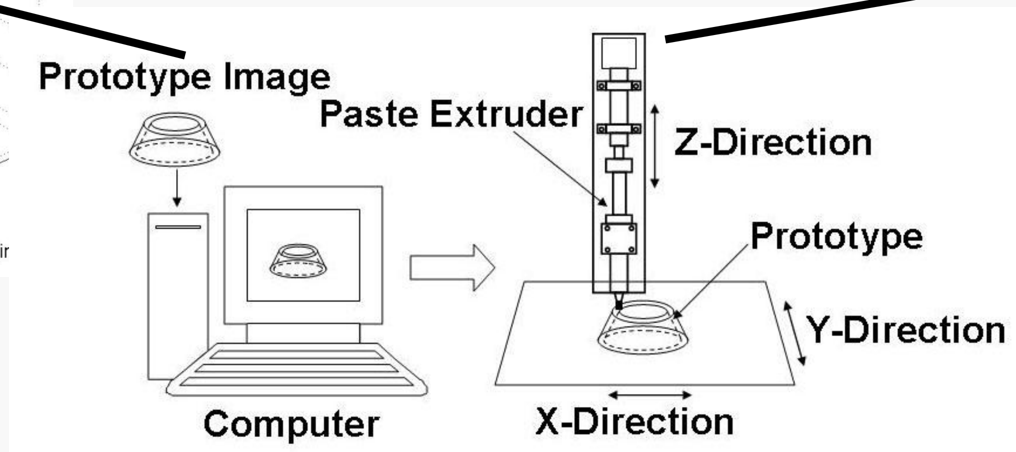
Computer Controlled part Repair with the LAMP System

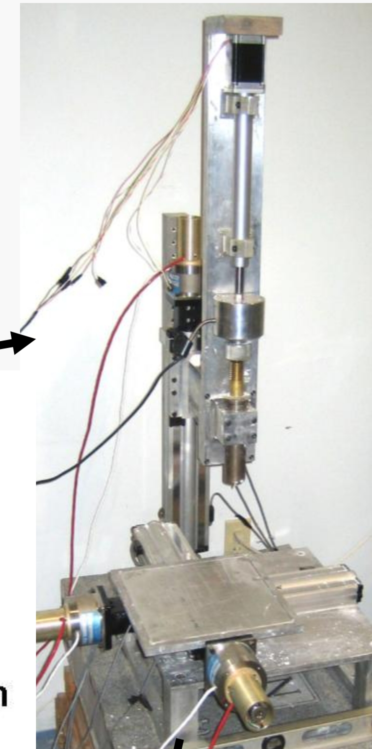




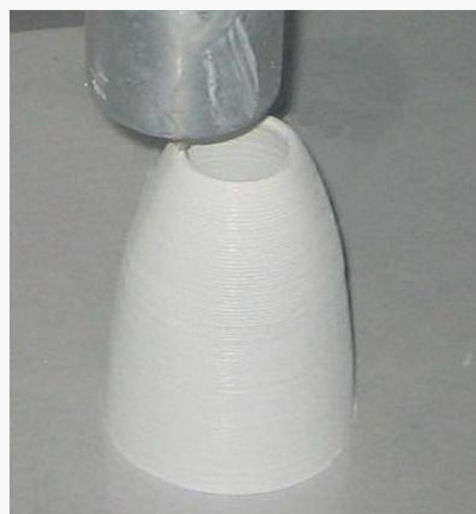
Freeze-form Extrusion Fabrication (FEF)

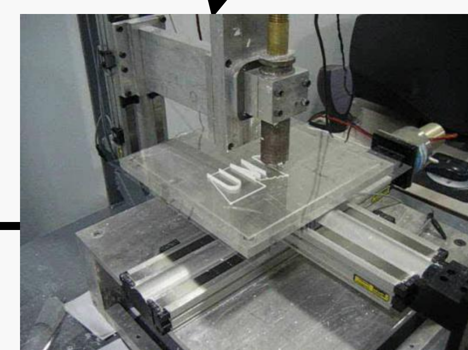




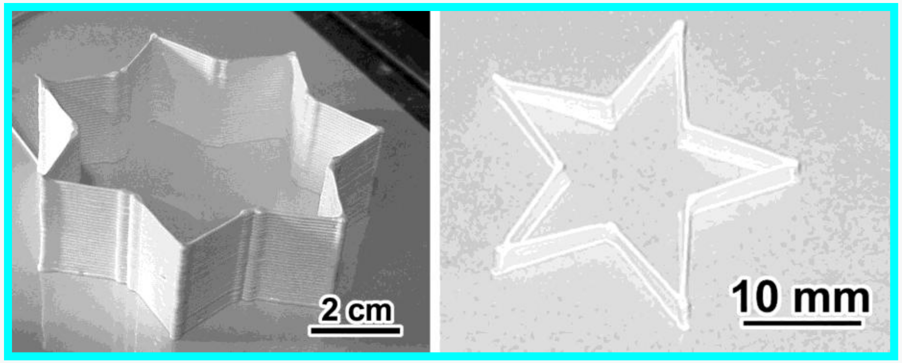


FEF system inside a freezer

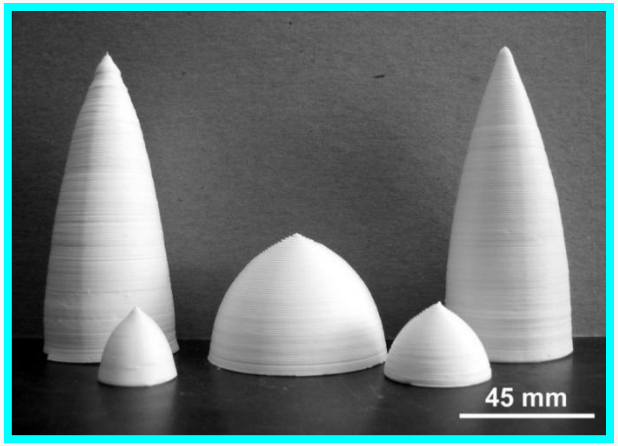




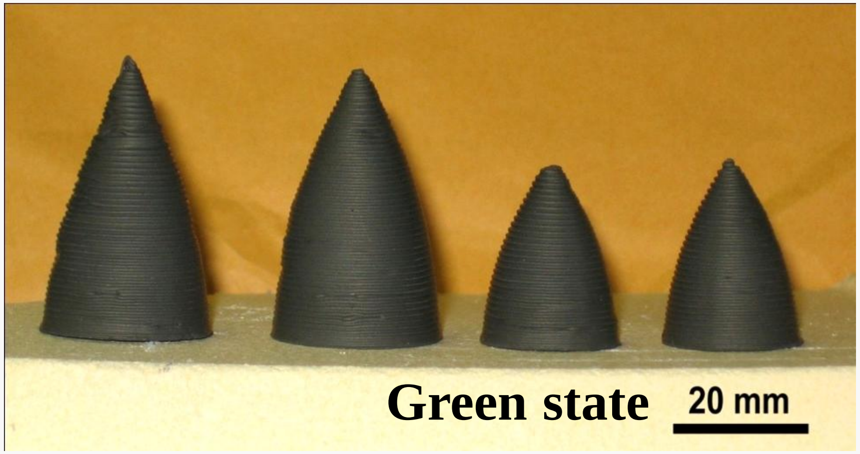
Sample Parts built by FEF



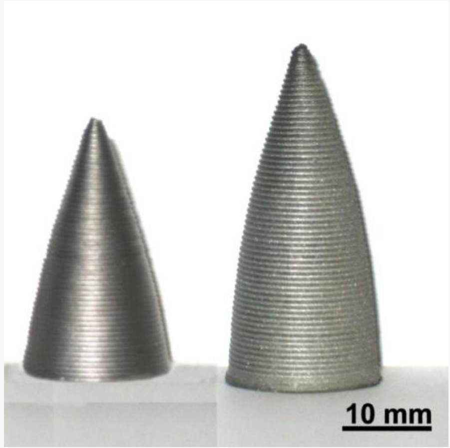
Green Al_2O_3 polygonal shapes



Sintered Al_2O_3 cones

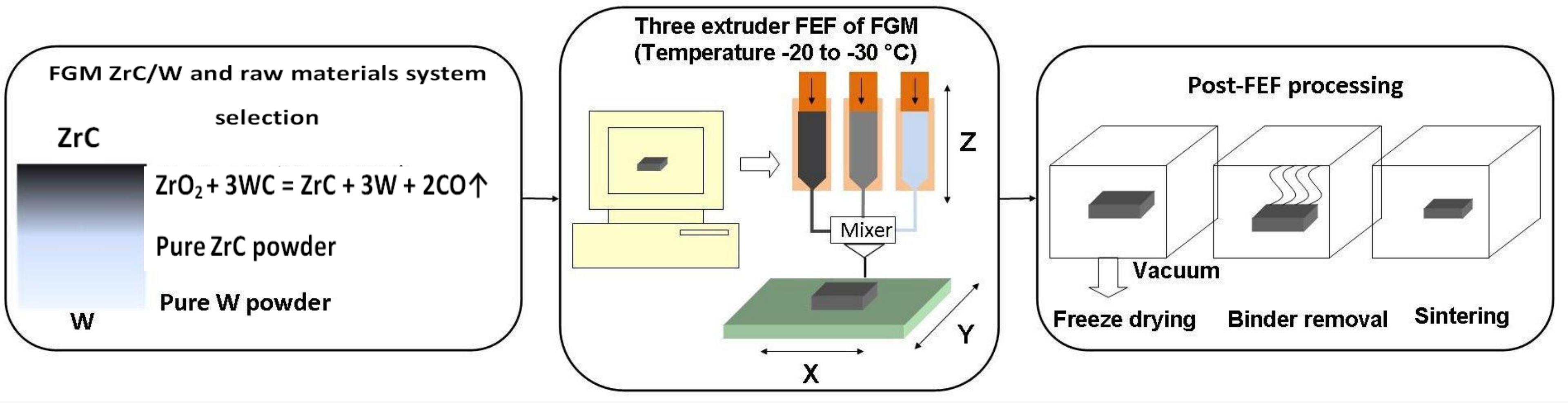


Green ZrB_2 cones

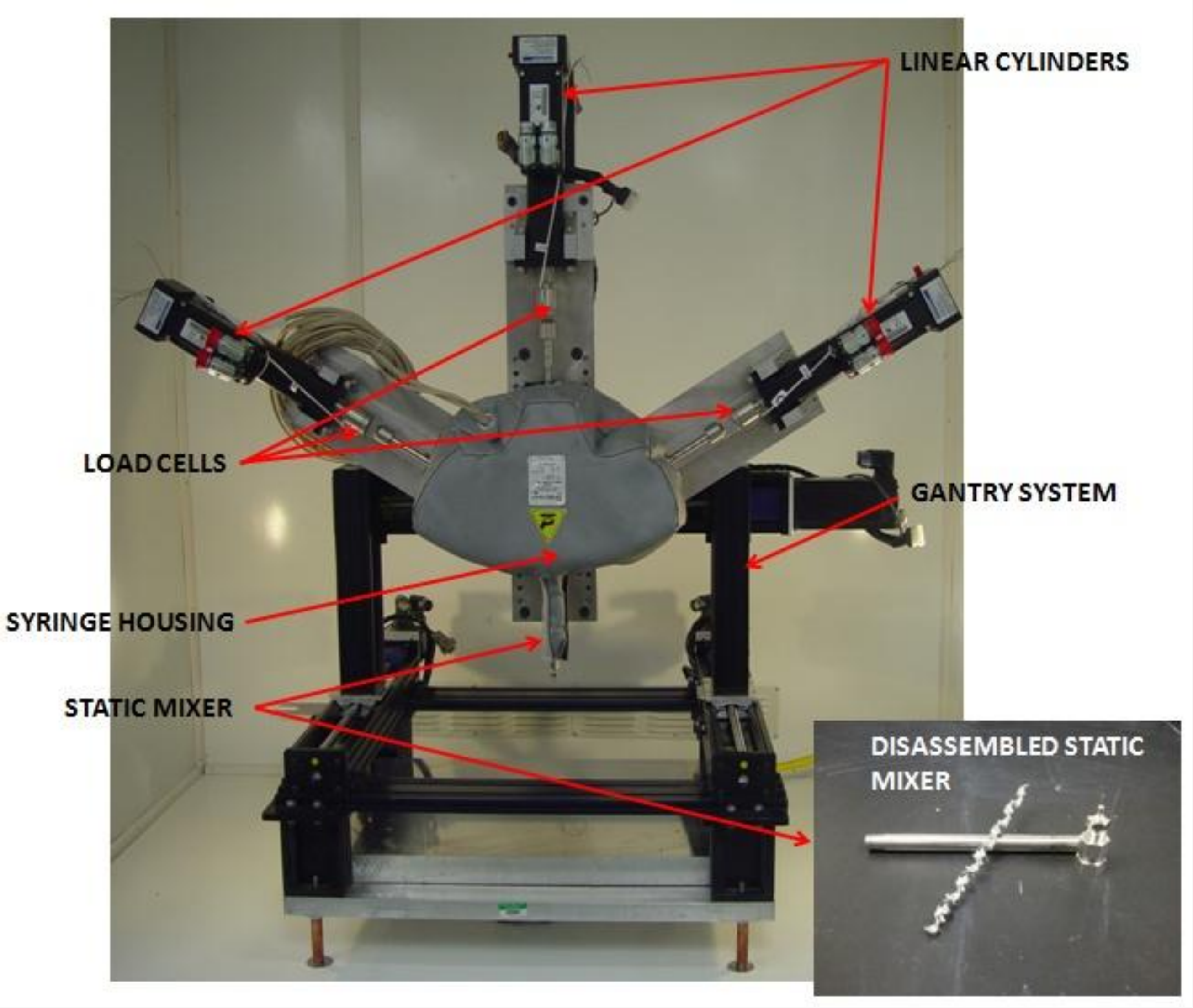


Sintered ZrB_2 cones

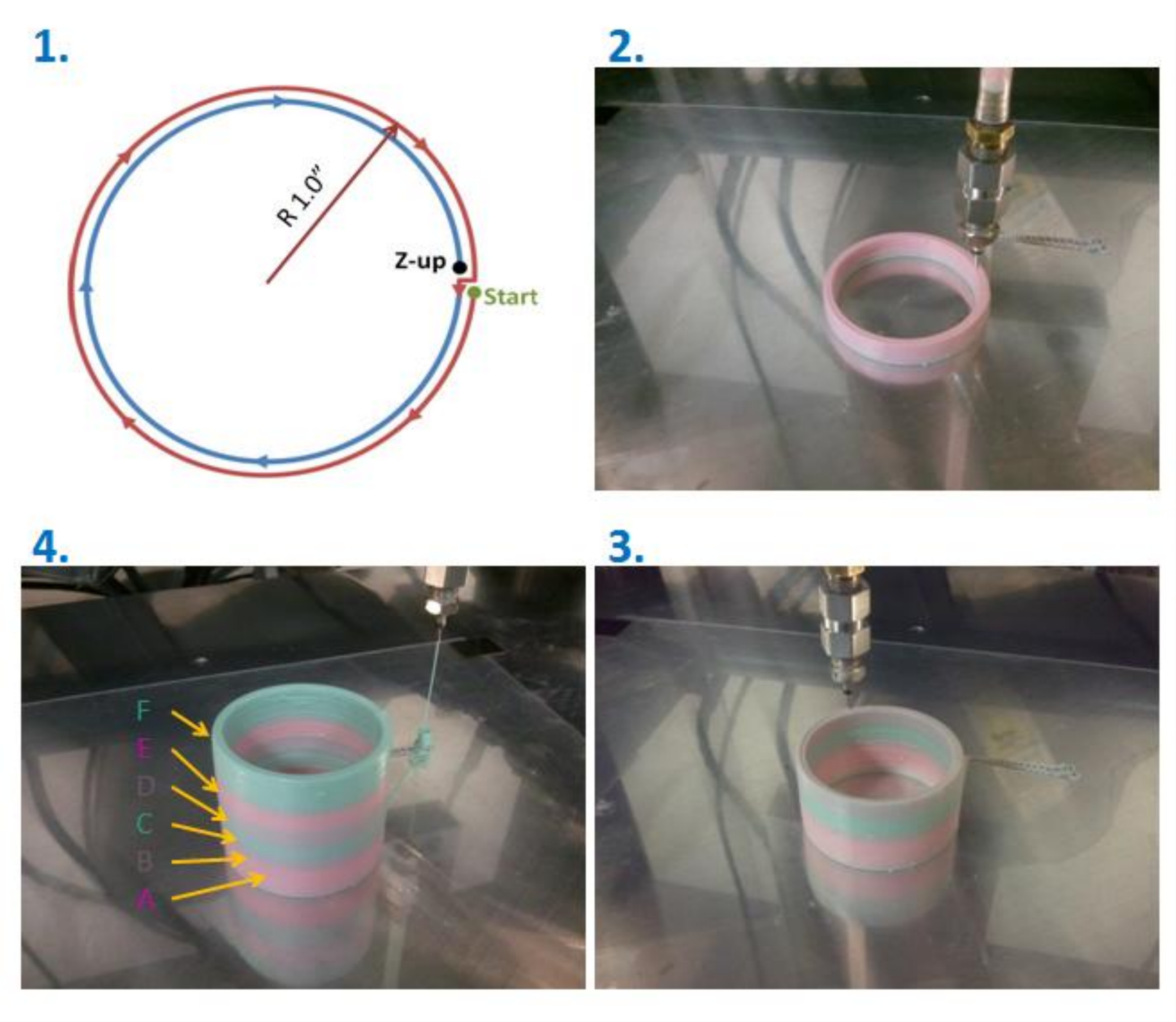
FGM Building Process Using a Triple-Extruder FEF Machine



Triple-Extruder FEF Machine



Triple-Extruder FEF Experimental Results



Intelligent Integrated Manufacturing and Cyber Physical Systems

a. Model-based Supply Network

b. Virtual Process Conceptualization and Operation

c. Intelligent Product Definition Model

d. Advanced Robotics

e. Cyber Physical Systems

f. Model-based Operations and Systems

Comments on Intelligent Integrated Manufacturing and Cyber Physical Systems

- The listed research topics are all fine. Collectively they represent a fairly complete “Intelligent Integrated Manufacturing” portfolio.
- I suggest modifying ‘Model-based Operations’ to “Model-based Operations and Systems” because many products and components are made by multiple manufacturing operations, not a single operation. How to integrate and optimally configure multiple operations into a system is a critical issue, and a model-based approach can be used best for that purpose.
- I feel that “Advanced Robotics” is most critical for NASA in this area because of the need for highly intelligent and autonomous operations during the flight for space exploration and the tasks conducted in the space station, Mar, Jupiter, etc.

Electronics and Optics Manufacturing Processes

a. Photovoltaic

b. Optics Fabrication

c. Special Electrical Process

d. Large Ultra-light Precision Optical Structures

I am not very knowledgeable in this topic area. The listed research topics look fine to me. I have no suggestion for this area.

Sustainable Manufacturing

a. Affordability-driven Technologies

b. Environmental Technologies -> Environment-driven Technologies

c. Green Production Processes

d. Advanced Energy Systems -> Advanced Energy Manufacturing Systems

e. Lifecycle Product and Process Design (or E^3 Technologies)

Comments on Sustainable Manufacturing

- The word affordability is normally associated with economic impact, not environmental impact. But the word affordability here implies environmental impact, which is different from the common use.
- It is not clear what ‘Environmental Technologies’ means. I think that “Environment-driven Technologies” would be a better term.
- It is not clear what ‘Advanced Energy Systems’ means, so I suggest modifying it to “Advanced Energy Manufacturing Systems.”
- I would think that in sustainable manufacturing, we should consider all of environmental, energy, and economic (E^3) impacts. Perhaps a new topic such as “Lifecycle Product and Process Design” or “E^3 Technologies” could be added to the list.

Nondestructive Evaluation (NDE) and Sensors

a. NDE Complex Built-Up Structures

b. Computational NDE

c. Combined NDE and Structural Analysis

d. Autonomous Inspection

e. Real-time Comprehensive Diagnostics

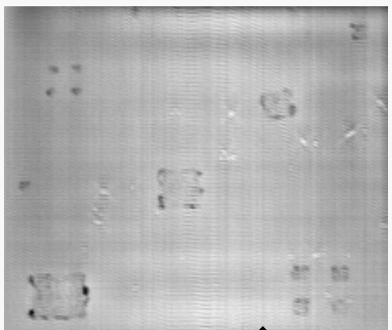
Comments on Nondestructive Evaluation (NDE) and Sensors

- The listed topics look fine to me. The only suggestion I have is to include other techniques besides ultrasonic NDE under the Computational NDE, such as eddy current, microwave, and millimeter wave based NDE technologies. I also suggest including sensor fusion, i.e., fusion of data obtained from different NDE techniques.
- In the column “Steps to TRL 6” there were numbers including 2013, 2016, 2023 and 2025 given. They should be removed because it is not clear what these numbers indicate.

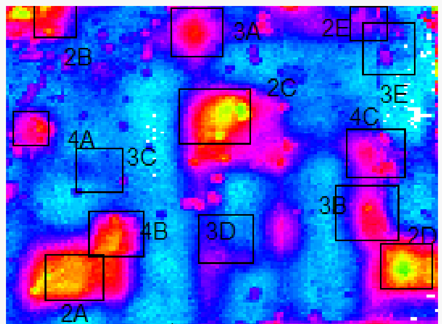
Multi-modal NDE for Corrosion Detection

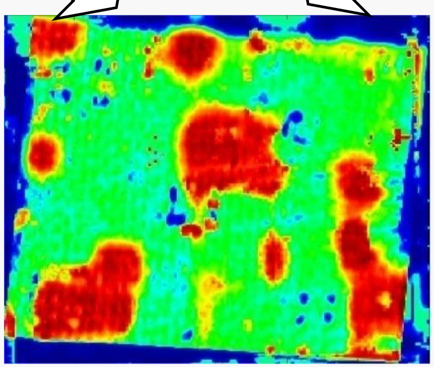
Microwave and Eddy Current Images of a Multi-layer Lap Joint

Microwave Image of Corrosion



EC Image of Corrosion





Fused MW and EC Images

Objective

Multi-modal NDE development for detection of corrosion under paint and lap joints.

Approach

- Develop techniques based on microwave, eddy current and other methods to detect and evaluate corrosion.

- Develop data fusion algorithms for detection and characterization of corrosion.

Application: Aging aircraft corrosion detection and evaluation.

Model-based Certification and Sustainment Methods

a. Physics-based design models

b. Strategies for Reliability

c. Damage Prediction

d. Integrated Lifecycle Tools

e. Methods and Processes for VDFL

The listed research topics look fine to me. I have no suggestion for this area.

Loads and Environments

a. Combined Environments

b. Improved Methods for Accurage Local and Global Loads and Environments

c. Test Validation

d. Design for Monitoring Strategies

e. Mission Loads and Environments Modeling

f. Autonomous In-flight Mitigation Strategies

Comments on Loads and Environments

- The listed research topics look fine to me.
- In the column “Steps to TRL 6” the wording “Analytical model for correlation in a lab environment” was used for all of topics c, d, and e. More distinguishable statements should be given for the different topics.

Answers to Posed Questions (1)

- What are the top technical challenges in the area of your presentation topic?
  - Accurate predictions based on multi-scale modeling and simulation
  - Ability to make 3D complex parts with high precision, high strength, and functionally gradient properties
- What are technology gaps that the roadmap did not cover?
  - Multi-scale modeling and simulation
  - Nanomanufacturing
  - Lifecycle Product and Process Design (or E^3 Technologies)
- What are some of the high priority technology areas that NASA should take?
  - Advanced robotics
  - Autonomous fabrication, repair and assembly at the point of use
  - Functionally gradients composites capable of surviving ultra-high temperature environments

Answers to Posed Questions (2)

- Do the high priority areas align well with the NASA's expertise, capabilities, facilities and the nature of the NASA's role in developing the specified technology?
  - Definitely.
- In your opinion how well NASA's proposed technology development effort is competitively placed.
  - Very competitively placed; however, NASA could leverage its research efforts on related research performed at universities (e.g., NSF funded research centers) and non-NASA national labs.
- What specific technology we can call it as a "Game Changing Technology"?

  Many of the technologies on the roadmap are game-changing technologies. The following lists two of such technologies:
  - Intelligent Product Definition Model
  - In-Space Assembly, Fabrication and Repair
  - Combined NDE and Structural Analysis

Answers to Posed Questions (3)

- Is there a technology component near the tipping point? (tipping point: technology insertion with small additional investment)?
  - Composites (especially PMC) manufacturing
- In your opinion what is the time horizon for technology to be ready for insertion (5-30 year)?
  - It depends on the specific technology. Some of the technologies (e.g., PMC manufacturing) may be ready for insertion in 5-10 years, while some others (e.g., large-scale nanomanufacturing) may take 10-20 years.
- Provide a sense of value in terms of payoffs, risk, technical barriers and chance of success.
  - Many of the research topics in the roadmap will contribute significantly to meeting non-NASA aerospace technology needs and non-aerospace national needs, in addition to NASA's own benefits. The risk and technical barriers are too high for industry to take on the research without government support. The chance of NASA success is high.