Additive Manufacturing Technologies for Aerospace Applications

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Outline

• Applications and NASA Strategic Thrusts
• Additive manufacturing capabilities
• Component applications
Additive Manufacturing Technologies

**Direct Write Printing**
Controlled dispensing of inks, pastes, and slurries.

**Fused Deposition Modeling**
Plastic is heated and supplied through an extrusion nozzle and deposited.

**Binder Jetting**
An inkjet-like printing head moves across a bed of powder and deposits a liquid binding material.
Components for Turbine Engine Applications

Turbine Engines - Targeted Components (CMCs and PMCs)

- Fan Duct
- Combustor Liners
- Shrouds & Vanes
- Exhaust Components

NASA CMC Components from Conventional Fabrication Methods

- Oxide/Oxide Mixer Nozzle
- SiC/SiC Combustion Liners: Outer Liner and EBC Coated Inner Liner
- EBC Coated SiC/SiC Vanes

NASA CMC Components from Conventional Fabrication Methods

EBC Coated SiC/SiC Vanes
Components for Electric Motor Applications

Electric Motors - Targeted Components (structural, functional, and electrical)

Axial Flux Machine
- Stator
- Magnet(s)
- Rotor
- Housing

Radial Flux Machine

Electrified Aircraft
- STARC-ABL
- NASA 15-PAX tiltwing aircraft
- Uber Elevate

NASA Aeronautics Research Six Strategic Thrusts
3. Ultra-Efficient Commercial Vehicles
   - Pioneer technologies for big leaps in efficiency and environmental performance
4. Transition to Low-Carbon Propulsion
   - Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Achieve and exceed N+2 and N+3 goals for increased efficiencies and reduced emissions.
Binder Jet Additive Manufacturing of SiC

An inkjet printing head moves across a bed of powder and deposits a liquid binding material.

Binder jet printing capability allows for powder bed processing with tailored binders and chopped fiber reinforcements for advanced ceramics.
ExOne Innovent

Constituents

Binder Jetting of SiC Fiber / SiC Matrix Composites

Fiber Reinforced Ceramic Matrix Composite

High pressure turbine cooled doublet vane sections.

SiC powder loaded SMP-10

Si-TUFF iSiC fibers
(Advanced Composite Materials, LLC)

~70 µm long and ~7 µm in diameter

SiC powder

SiC powder

SiC Powder

SiC Powder

SiC Powder

SiC Powder

SiC Fibr

SiC Powder

SiC Powder

SiC Powder
Binder Jetting of Metallic Parts
Demonstration of Polymer Components from FDM

Inlet Guide Vanes from ABS and Ultem 1000

High temp. polymers with chopped carbon fiber reinforcement.

The focus is on unique structures, high temperature capability, and fiber reinforcement.

Lightweight Structures

Acoustic Liner Test Articles

Engine Panel Access Door

FDM Process

Fortus 400

National Aeronautics and Space Administration
Additive Manufacturing by Fused Deposition Modeling Simplifies Engine Acoustic Liner Fabrication

Current manufacturing approach requires metal forming, bonding, and drilling

Integral facesheet/honeycomb structures fabricated in one step using fused deposition modeling (FDM)

Fabricated with Ultem 9085 thermoplastic ($T_g=367^\circ$F), Application temperature of 200$^\circ$F

Optimized acoustic absorber would reduce engine fan noise
FDM of Composite Filaments for Multi-Functional Applications

Potential Missions/Benefits:
• On demand fabrication of as needed functional components in space
• Tailored, high strength, lightweight support structures reinforced with CNT
• Tailored facesheets for functional properties, i.e. wear resistance, vibration dampening, radiation shielding, acoustic attenuation, thermal management

Filaments used: ABS-standard abs, P-premium abs, CNT-w/carbon nanotubes, C-w/chopped carbon, Home-lab extruded filament

Highest strength and modulus in CNT reinforced coupons versus standard ABS Coupons. Less porosity for lower print heights.
Hyrel Hydra 645: build volume
600x400x500mm X/Y/Z

MK1-250 EXTRUDER
Standard Hot Flow
For the most common 1.75mm filaments on the market with service temperatures up to 250°C. ABS, Nylons, PLA, PETT, etc.

MK1-450 EXTRUDER
Very Hot Flow
For Exotic 1.75mm filaments with service temperatures between 250-450°C. Polycarbonate, PEEK, Ultem, Carbon Fiber.

MK2-250 EXTRUDER
Flexible Hot Flow
For Flexible 1.75mm filaments with service temperatures up to 250°C. BendLay, FilaFlex, NinjaFlex, etc.

VOL-25 EXTRUDER
Warm Flow
For emulsifiable materials with service temperatures up to 100°C, such as waxes and glues.

SDS-10 EXTRUDER
Sterile, Disposable
For low viscosity, room temperature materials with 10cc syringes. Liquids, Gels, Biologicals, etc.

SDS-60 EXTRUDER
Sterile, Disposable
For low viscosity, room temperature materials with 60cc syringes. Liquids, Gels, Biologicals, etc.

QUIET STORM COOLING FAN
Additional, Directed Cooling
Programmable cooling where you want it. Position, Program, Peace of Mind

ST1 ROUTER
Engrave, Cut, Route
For simple operations only possible with a spindle tool. NOTE: you must supply your own fixturing. Paper, Wood, Metals (Drilling only), PCB (Routing), Acrylic
Multi-Material Tensile Testing of Higher Temp. Ultem

Hyrel Hydra 645

Multi-material print

Tensile Testing

(DIC)
Mark Forged – 3D printing of Fiber Reinforced Parts

- Higher strength-to-weight than 6061 Aluminum
- 24X stronger than ABS

Two print heads: one for nylon and the other for fiber reinforced composite.
NScrypt Capabilities and Benefits

- Ability to host up to four separate materials and print on curved surfaces or print 3D structures.
- Motion control accuracy of ±5 microns and repeatability of ±2 microns in XY Micro-dispensing pump has volume control of dispensed materials of 100 picoliters.
- Ability to print a wide variety of ceramic pastes (structural and functional), electronic pastes, adhesives, solders, bio-materials.
- Direct writing with no contact or masks as for screen printing
- Clean starts and stops

**NScript Print Examples: Electronics**

Resistors with 75µm line width and 200 µm pitches dispersed.


Conductors Dispensed by NScript.


Planar spiral inductors

Close up of interdigitated capacitor and its line features
3D Printed Buried Electronics

Solid, monolithic piece

Multi-material
- Clear polycarbonate
- Blue ABS
- Silver flake
- Carbon
- Dielectric
- Active device (silicon)
- Battery

Multi-pump
- Thermal plastics
- High viscosity paste

Structure cut and sanded

ABS
Silver
ABS
Polycarbonate

Printing of Multi-materials
AM and Hybrid Approaches for Electric Motor Components

Electric Motors

Components of a Commercial Axial Flux Motor

NASA Electric Motor with AM Components

Stators

Litz Wire Coreless Stator

PCB Coreless Stator

Iron Core Stator with Direct Printed Coils

Stator Constituents:
- Conductor: copper, silver.
- Insulators: coatings, dielectrics, epoxy, high temp. polymer.
- Soft magnets (for cores): iron alloys.

Rotors

Additively Manufactured Rotor Plate

Rotor Constituents:
- Permanent magnets.
- High strength structure (typically metallic).
PCB Stator Concepts

Direct Printed Silver Conductor Layer

Printed strain gages.

Direct Printed Dielectric Layer
Samples were printed on the nScrypt 3Dn-300.

Crucial Parameters:
- Print Speed
- Dispensing Pressure
- Nozzle Diameter
- Print Offset
- Valve Opening

Direct Printing for Innovative Stator Designs for Electric Motors
Advanced Higher Electrical Conductivity Silver System Through Carbon Nano-Structure Additions and Sintering Processes (GRC)

Carbon Nanostructure Additions

Graphene and Carbon Nanotubes

Much easier and faster iterations for investigating affects of additions to pastes compared to copper wire/stock (cold rolling and mixing issues).

Sintering optimization by investigating offset distance, kV setting, pulses, duration, and nano-sized silver particle additions.

Photonic Sintering

Investigating the use for photonic sintering for printed silver inks.

• Rapid post processing of conductive patterns
• Few second to minute processing times without damaging/heating the substrate
Summary

• NASA GRC has several additive manufacturing capabilities
  – Binder jetting for ceramics and metals
  – FDM of polymers for lightweight multifunctional applications
  – Direct printing of conductors and sensors

• The AM capabilities and experience can be leveraged for partnerships in other areas.