Why In-Space Manufacturing??

- Reduce Launch Burden Related to Cargo Delivery to Space (image credit NASA)
- Reduce launch mass through in-situ resource use (image credit ICON)
- Moon to Mars Objectives (image credit Redwire)
- Recycling and Trash Management (image credit NASA)
- On-demand manufacturing of critical parts and tools
- Build objects too big or fragile to launch

Bring ➔ Recycle & Reuse ➔ In-Situ Resource Utilization
In-Space Manufacturing Goals & Objectives

1) Develop a Space Economy

**M2M Goal Supported:** LI-4L, Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

**Applications:** Manufacture goods for Government and Industry
- Leverage the microgravity environment
- Enable Outfitting of Habitats
- Manufacturing goods in space for Earth

**Focus:** AM/Welding of Metals, Polymers, Electronics, Logistics Reduction, Biomanufacturing, and Computational Modeling/Digital Twins

2) Enable Sustainable Deep Space Missions

**M2M Goals Supported:** LI-8L, Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence; and TH-4LM, Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.

**Applications:** Living Sustainably on the Lunar and Martian Surfaces
- Medical Devices
- Crew Tools & Engagement
- Habitats Outfitting & Infrastructure
- EVA Aids (ex. modular excursion devices)

**Focus:** Enabling living and working in space to be sustainable → reducing operations cost.

Takeaway: NASA is investing in the development of enabling manufacturing technologies for use in space.
Reformulation Preview – In Work

Technology Development Needs Addressed by ODME

| ESDMD/EC     | Infusion of ODME tech for REALM RFID and ECLSS sensors | STARPort
<table>
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<tbody>
<tr>
<td>SOMD/HRP</td>
<td>Infusion of ODME tech for biosensors and extreme environments</td>
<td>777, 948, 1160, 1218</td>
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<tr>
<td>SOMD/InSPA</td>
<td>Commercial infusion of ODME tech for semiconductors and microelectronics</td>
<td>895, 926, 1065 1066, 1364</td>
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**Project Goals**

**Goal #1**
Develop and integrate deposition systems for multilayer electronic devices through parabolic flight demonstrations culminating in an Interim Design Review (IDR).

**Goal #2**
Develop and test the semiconductor manufacturing technologies and support parabolic flight testing to demonstrate critical functions.

**Project Objectives**

**Objective #1**
Development, ground testing, and support of parabolic flight testing for direct ink write process and applications including via filling and chip placement. 

**Objective #2**
Development and ground testing of the Electrohydrodynamic Inkjet materials and process including feature resolution characterization, and parameter optimization.

**Objective #3**
Conduct an Interim Design Review of an Integrated Printed Electronics Printer Module

**Objective #4**
Demonstrate the feasibility of the printing of electronic devices by a Laser Ablation Deposition process.

**Objective #5**
Development of laser curing for dielectric and conductive inks through a laboratory ground demonstration.

**Acronyms:**
EC = Exploration Capabilities
HRP = Human Research Program
InSPA = In Space Production Applications
REALM = RFID Enabled Autonomous Logistics Management
RFID = Radio Frequency Identification
ECLSS = Environmental Control and Life Support Systems
FO = Flight Opportunities
ISM ODME Project Organization
**Exploration & Science**

*NASA Exploration and Support “In Space for Space” development*

- ECLSS Sensors
- Wearable sensors
- Printed Power & Energy
- Logistics – spares and upgrades for missions

**Commercialization**

*Support “In Space for Earth Applications” development*

- Semiconductors

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**Academic**

- University of Louisville
- University of Alabama Huntsville
- Appalachian State
- Auburn University
- Boise State
- Georgia Tech
- CalTech
- Iowa State University
- Florida A&M University
- Oregon State University
- West Virginia University
- Youngstown State University
- University of Wisconsin
- University of Wyoming
- University of Delaware
- University of Texas El Paso
- Mississippi State
- Arizona State University
- University of Delaware
- Stanford University
- The Ohio State University
- University of Texas at El Paso

**NASA Centers**

- Marshall Space Flight Center
- Ames Research Center
- Johnson Space Center
- Kennedy Space Center
- Goddard Space Flight Center
- Jet Propulsion Laboratory
- Glenn Research Center
- Langley Research Center
- Armstrong Flight Research Center

**Industry/Government**

- Techshot
- Redwire Space
- Cornerstone Research Group
- LambdaVision
- Faraday Incorporated
- Laboratory for Physical Sciences
- Intel
- Fujifilm
- Axiom Space
- ISS National Lab
- Goeppert
- NextFlex
- nScrypt
- Multi3D

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**ODME Partnership Map**
**ODME Leveraged Collaborations**

### Research/infusion focus:
- **GCD** - Overall direction and inhouse dev of materials and systems
- **STMD/FO** - Validation suborbital testing
- **EPScoR & SBIR** projects – focused tech dev projects to support NASA inhouse research
- **CIF, TIP, CANs** (IRAD funding) - support NASA inhouse funding and workforce development

### STMD/ GCD (Game Changing Development)
- STMD/ Flight Opportunities
  - 5 Flights in FY23 for ODME-related technologies
  - Advanced Toolplate, EHD Inkjet, SEADS Semiconductors, MSTIC Semiconductors, FAME crystal fluid flow

### ESDMD/ EC (Exploration Capabilities)

### EPScoR (Established Program to Stimulate Competitive Research)
- 4 in FY22 with WVU (Sierros) and Boise State (Estrada, Deng, Harish)
- New NSF/EPScoR research track for Additive Electronics
- Probable 3-4 Track 4 Projects in FY24

### NSTGRO (NASA Space Technology Graduate Research Opportunities)
- Adding a new researcher in FY24 from University of Wisconsin on EHD Inkjet

### SBIR (Small Business Innovation Research)
- FY24 STTR New Printed Electronics - 3 newly awarded projects for FY24

### CIF (Center Innovation Fund)
- MSFC (Sansoucie/Hill/ Jones)
- AI CIF for 2023

### CAN (Cooperative Agreement Notice)
- 5 in FY22 with 4 Universities
- Additional 2-3 planned for FY24

### NSF University Consortium (ATOMIC)
- Penn State, Boise State, and Rice University

**MUREP Funding**
TRL Progression

ODME

**GCD (Key) Milestone**

**Controlled Milestone**

**Project Milestone**

**Thin Film Technology**

**Multilayer Technology Development - TRL**

**AstroSense FHE Sensor Device Development - TRL**

**FY21**

- Initial Parabolic Flight Campaign (Iowa and Space Foundry)

**FY22**

- Second Parabolic Flight Campaign (Iowa)
- Second Parabolic Flight (Space Foundry)
- Thin Film Technology Evaluation Final Report

**FY23**

- Verification on prototype multilayer devices
- Down Select Milestone Thin Film Deposition Method
- Delivery of Wireless Potentiostat System
- Delivery of AstroSense Beta Unit

**FY24**

- EHD Inkjet Test On Advanced Toolplate
- Advanced Toolplate Parabolic Flights

Draft – based on previous draft plan. Reformulated chart in work.
FY23 Accomplishments – Advanced Toolplate Development

The ODME Advanced Toolplate is a major technology development for Multi-material 3D printing.

- The new Advanced Toolplate is 40% the volume of the previous Toolplate.
- Generation 3 tools are 35% smaller than generation 2, enabling a doubling in the number of tools on the Toolplate from four (4) to eight (8), thus doubling the ODME process capability and minimizing crew time in changeovers.

- Development of the Advanced Toolplate and integration with the ODME Print Module was completed in July 2023.
- A parabolic flight campaign to test the Advanced Toolplate and new toolheads was scheduled for August but has been rescheduled by the flight provider to October 2023. (Flight Opportunities Funded)
- New toolheads are also being developed for the Advanced Toolplate, including EHD inkjet (semiconductors) and Faraday electrodeposition (Phase II SBIR).

Target applications for infusion:
- Semiconductors / commercialization
- Microelectronics for future missions
- Sensors – HRP and ECLSS
ODME is working with academic partners to develop a next-generation thin film deposition system for semiconductors and microelectronics. (ODME-funded research on labor and materials development. Flight Opportunities funded hardware development.)

- EHD inkjet uses an electric field rather than piezoelectric force for very precise deposition. This system has the potential to advance thin film deposition SOA into the nanometer range.
- ODME and Flight Opportunities have already completed two parabolic flight campaigns (120 parabolas) of zero gravity testing of this system prior to FY23. Two additional campaigns are planned for FY23.

- ODME, with the University of Wisconsin and Sciperio, are developing a new EHD inkjet toolhead for the Advanced Toolplate.
- A parabolic flight campaign to test the Advanced Toolplate and new toolheads was scheduled for August but has been rescheduled by the flight provider to October 2023.

Target applications for infusion:
- Semiconductors / commercialization
- Microelectronics for future missions
- Sensors – HRP and ECLSS

<table>
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<th>SPEC</th>
<th>DMP-2850 IJ (Industry Std)</th>
<th>EHD Inkjet</th>
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<tr>
<td>Minimum feature size</td>
<td>30 microns</td>
<td>0.5 microns</td>
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<tr>
<td>Ink viscosity</td>
<td>4-8 centipoise</td>
<td>0.1 - 500 centipoise</td>
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<tr>
<td>Ink surface tension</td>
<td>28-32 dynes/cm</td>
<td>1 - 800 dynes/cm</td>
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<tr>
<td>Droplet size</td>
<td>1pL - 10pL</td>
<td>0.1fL - 10pL</td>
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ODME is developing the capability to fabricate more complex printed electronics comprising multiple layers on flexible and non-flexible substrates. ODME has a collaborative project with Auburn University on this research. ODME and Auburn have made significant progress in the second year of their research on multilayer processing. Complete:

- Development and evaluation of multiple multilayer deposition processes and materials.
- Successful printing of a Multilayer flexible printed circuit board.
- Demonstrated with a functional LED blinking circuit board.
- ODME and Sciperio also developed and fabricated a functional multilayer CO2 sensor.

Target applications for infusion:
- Microelectronics for future missions
- Sensors – HRP and ECLSS
Tech maturation through ODME development is a critical phase of commercialization of printed semiconductors. ODME is collaborating with Intel, Axiom Space, TEL, Arizona State, and Univ. of Wisconsin to develop printed RERAM memory chips for microgravity production. (ODME-funded research on labor and materials development. InSPA funding microgravity development by partner companies.)

- ODME EHD Inkjet process used to print nanocircuits of printed memory chips.
- The EHD process is significantly faster with much higher product yields, and it eliminated a secondary etch process required by current ground-based semiconductor fabrication.
- ODME and the Intel team have successfully demonstrated this technology on the ground in FY23, with a planned demonstration on parabolic flight testing in October.

Target applications for infusion:
- Semiconductors / commercialization
FY23 Accomplishments – Parabolic Flight Campaigns

ODME has extensively used the Flight Opportunities suborbital parabolic flights program for validation of several newly developed technologies. For the EHD Inkjet technology that has developed into the lead technology for printed semiconductors, ODME and FO conducted two full flight campaigns (120 parabolas) in FY21 and FY22. For FY23, ODME and FO have additional planned campaigns for tech validation.

Planned and Funded Parabolic Flight Campaigns for 2023

- ODME Advanced Toolplate – testing of new Advanced Toolplate and tools
- SEADS Semiconductors - testing of newly developed EHD inkjet process for printing semiconductor memory chips (InSPA Funded)
- EHD Inkjet Integration into Advanced Toolplate - testing of EHD inkjet head integrated into Advanced Toolplate

Target applications for infusion:
- Semiconductors / commercialization
- Microelectronics for future missions
- Sensors – HRP and ECLSS

GCD/ODME is Leveraging STMD Flight Opportunities investment into ODME tech maturation of microgravity technologies.
### ODME Project Assessment Summary

<table>
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<tr>
<th>Project Name</th>
<th>Performance</th>
<th>Comments</th>
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<td>C S T P</td>
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- **Technical** is **GREEN**. ODME and ODMM have finalized a technical approach on FabLab with Advanced Toolplate, using pooled resources. Task Order TO1 with TechShot has been updated for ODME only, which includes Advanced Toolplate. Also, Flight Opportunities has approved funding for a new Parabolic Flight printer and support to test the Advanced Toolplate in May 2023.

- **Cost** is **GREEN** and within budget with the contract holds and cancellations from recent GCD budget impacts. Overall ODME collaborations and internal development have been reduced to align with reduced GCD budget.

- **Schedule** is **GREEN**. ODMM and ODME have developed a new approach to the Advanced Toolplate with pooled available resources. GCD has re-funded the NextFlex project for development of flexible sensor platform. These delays have now been recovered in the schedule.

- **Programmatic** remains **GREEN**.

- **Technical** is **GREEN**. ODME is implementing a technical approach on the Advanced Toolplate. Flight Opportunities has also approved funding for a new Parabolic Flight printer and support to flight test the Advanced Toolplate in October 2023. **There may be risk going forward depending upon what path is chosen by GCD for ODME ISS orbital flight demonstration.**

- **Cost** is **GREEN** and within FY23 budget authority. Overall ODME collaborations and internal development have been reduced. Additional parabolic flight testing of the new Advanced Toolplate and EHD Inkjet/Semiconductors has been funded by Flight Opportunities and InSPA.

- **Schedule** is **GREEN**. ODME is developing and parabolic flight testing the new Advanced Toolplate in October and November 2023.

- **Programmatic** remains **GREEN**. **Continuation Review for ODME successfully completed at MSFC on July 21. New Project Plan and TRAIT analysis will be completed after action items responses are approved by GCD.**
On-Demand Manufacturing of Electronics is a critical need for future habitats and missions. The technology infusion plan involves sub-orbital flight tests (MISEE, Sounding Rocket, Multiple Parabolic Flights). Elements of the technology are being developed FY21-24.

- Applicable to current ISS operations and planned CLD Phase Over
- Applicable to Artemis II, Lunar Surface Habitat
- Applicable to M2M and future exploration missions
• ODME collaborates between 9 NASA Centers, 14 public or private companies, and 20 different universities.

• Published 17 collaborative research papers.
• Presented ODME project research at 4 conferences.
• Hosted MSFC visits for 10 of our external partners.
• The ODME team visited 4 academic or industry partners this year.

• The ODME project is developing technologies for the hardware required for on-demand electronics, sensors, and semiconductors in a microgravity environment. To develop these technologies, ODME has engaged multiple research universities and private companies to collaborate in the development of the hardware, materials, and processes required for the microgravity demonstration on the ISS. ODME is leading the tech development of new leading-edge technologies required for the manufacturing of semiconductors in space.