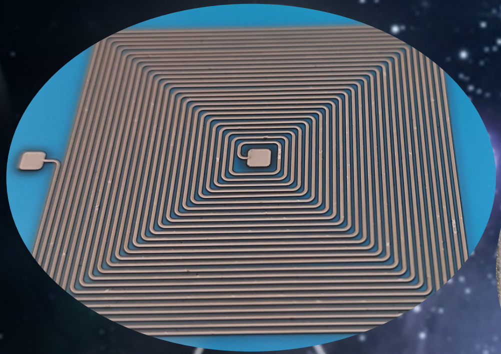
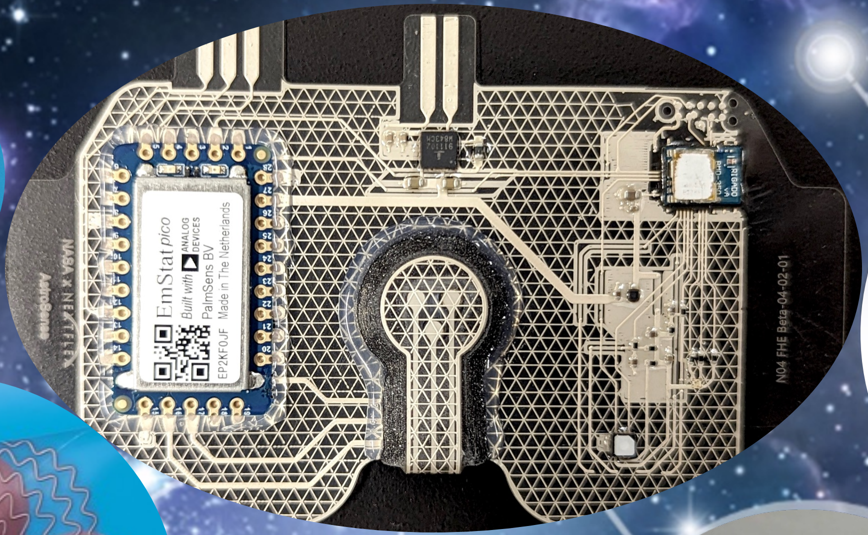
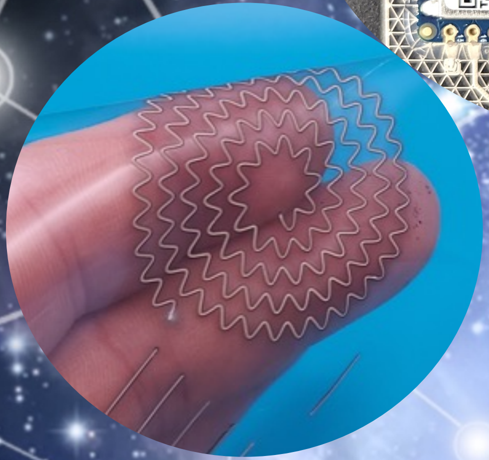
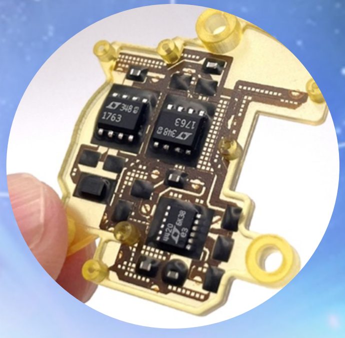
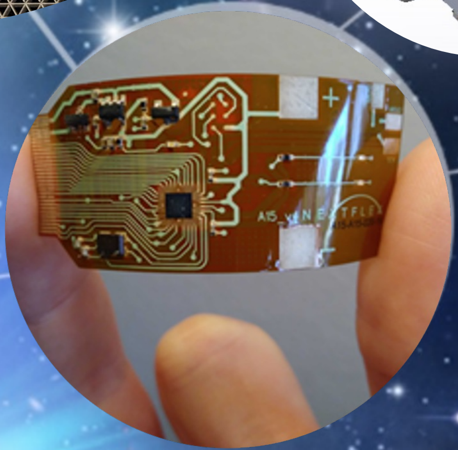
National Aeronautics and
Space Administration











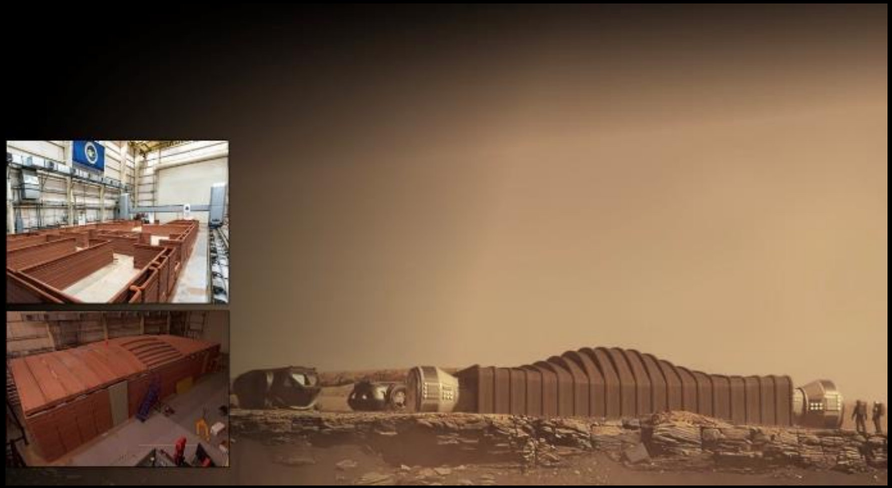
On-Demand Manufacturing of Electronics (ODME) APR: September 2023

Zach Courtright | **ISM Portfolio Manager** | FY23 ODME Annual Review Presentation | 09.22.23
zachary.s.courtright@nasa.gov

Why In-Space Manufacturing??

Reduce Launch Burden Related to Cargo Delivery to Space (image credit NASA)

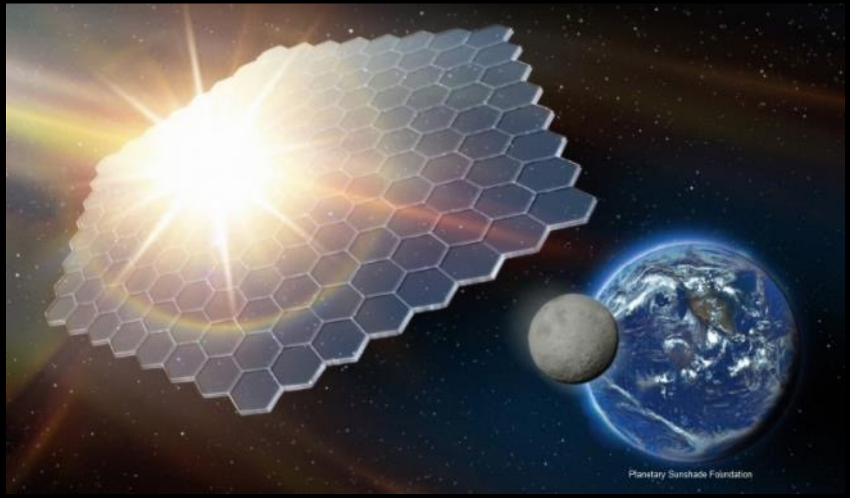
Reduce launch mass through in-situ resource use (image credit ICON)



Moon to Mars Objectives (image credit Redwire)

Recycling and Trash Management (image credit NASA)

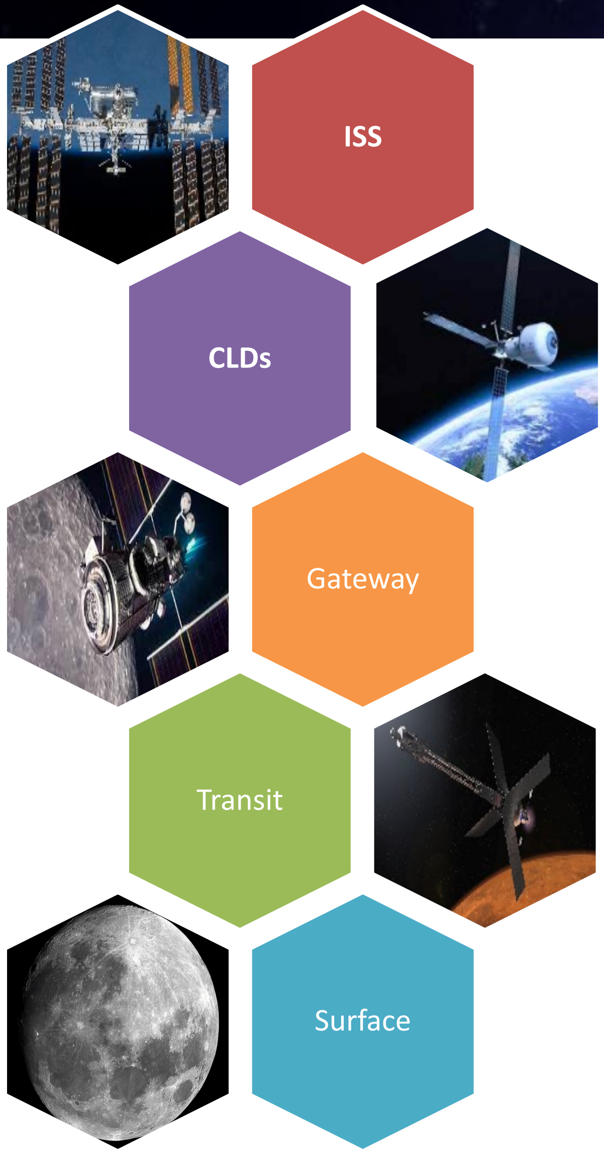
On-demand manufacturing of critical parts and tools



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

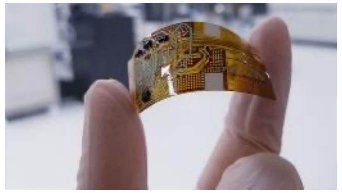
M2M Goal Supported: LI-4L, Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

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

FabLab (multimaterial printer for µg application)



Printed Electronics

Heat Exchangers

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.

On Demand Cast

Fasteners and Tools

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		STARPort
ESDMD/EC	Infusion of ODME tech for REALM RFID and ECLSS sensors	575,745, 1063
SOMD/HRP	Infusion of ODME tech for biosensors and extreme environments	777, 948, 1160, 1218
SOMD/InSPA	Commercial infusion of ODME tech for semiconductors and microelectronics	895, 926, 1065 1066, 1364

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

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		Notes
Objective #1	Development, ground testing, and support of parabolic flight testing for direct ink write process and applications including via filling and chip placement.	Parabolic Flights funded through FO
Objective #2	Development and ground testing of the Electrohydrodynamic Inkjet materials and process including feature resolution characterization, and parameter optimization .	GCD funds will target ground development maturing the technology through TRL 3-4 Parabolic Flights funded through FO and InSPA
Objective #3	Conduct an Interim Design Review of an Integrated Printed Electronics Printer Module	Pending approval of continuation to IDR
Objective #4	Demonstrate the feasibility of the printing of electronic devices by a Laser Ablation Deposition process.	Feasibility studies would target simple electronics printing; however, depending on testing results, active devices along with alloy deposition would be tested.
Objective #5	Development of laser curing for dielectric and conductive inks through a laboratory ground demonstration.	Development of laser curing would be limited to the primary electronic feedstocks such as conductive and dielectric materials

ISM ODME Project Organization

Technical Authority

Terry Jones
Chief Safety Officer

Christopher Roberts
Chief Engineer

Project Office

Zach Courtright
Project Manager

Lonette Jenkins-Bell
Project Coordinator

Rebecca Jeans
Resource Analyst

Frank Ledbetter
Senior Advisor

Sonny Mitchell
Senior Advisor

Bob Gower
Scheduler

John Vickers
Principal Technologist & SCL

Mike Barnhardt
Program Element Manager, GCD

Curtis Hill
ODME Principal Investigator
Dave McIntosh
Lead Systems Engineer

Marshall Space Flight Center

Materials & Processes
Jenny Jones and Cadre Francis

Space Systems Development
Curtis Banks, Liz Barrios, Leigh Elrod, Austin Fox, Jacob Jensen, Steven Peeples, Carol Putman, Diego Gomez Ruiz, Cameroun Sherrad, and David Wilkie.

Ames Research Center

Milton Cordeiro, Ami Hannon, Jessica Koehne, Jing Li, and Myeonglok Seol

Goddard Space Flight Center

Beth Paquette and Margaret Samuels

ODME Partnership Map

Exploration & Science

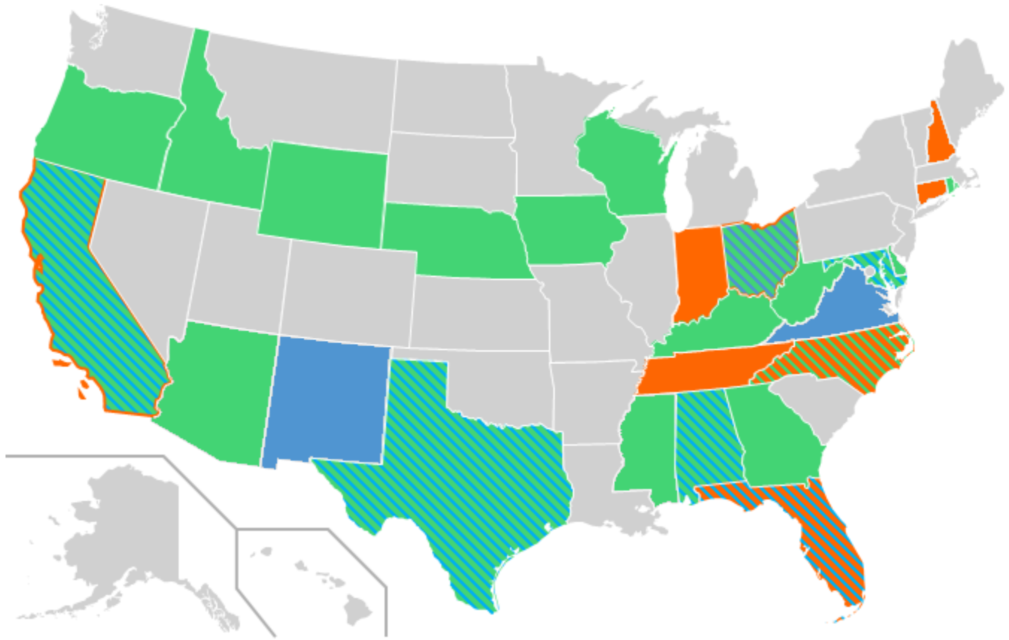
NASA Exploration and Support "In Space for Space" development

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

Commercialization

Support "In Space for Earth Applications" development

- Semiconductors



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

ODME Leveraged Collaborations

STMD/ GCD (Game Changing Development)

ESDMD/ EC (Exploration Capabilities)

STMD/ Flight Opportunities
- 5 Flights in FY23 for ODME-related technologies
- Advanced Toolplate, EHD Inkjet, SEADS Semiconductors, MSTIC Semiconductors, FAME crystal fluid flow

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
- MUREP Funding

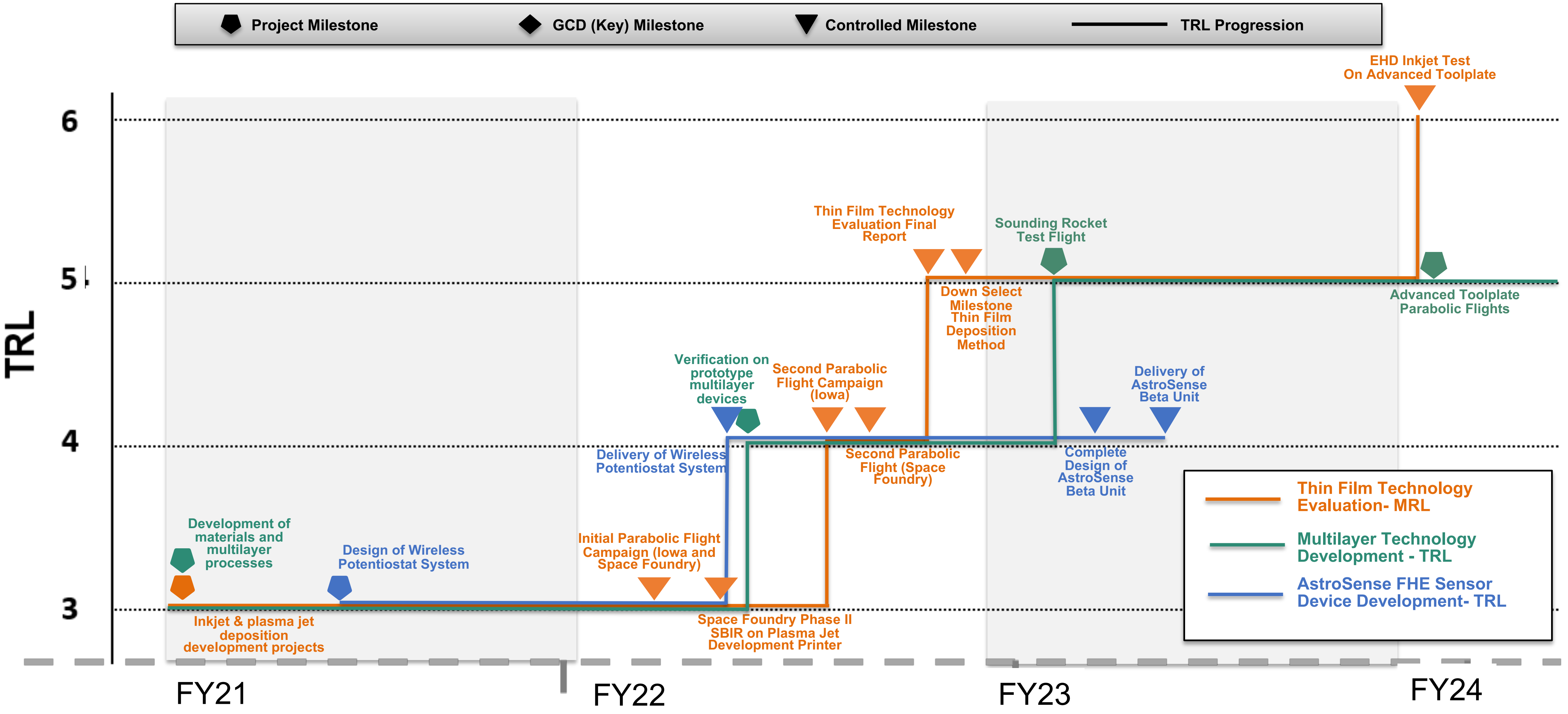
NSF University Consortium (ATOMIC)
- Penn State, Boise State, and Rice University

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 research and workforce development

Draft – based on previous draft plan. Reformulated chart in-work.

TRL Progression

ODME



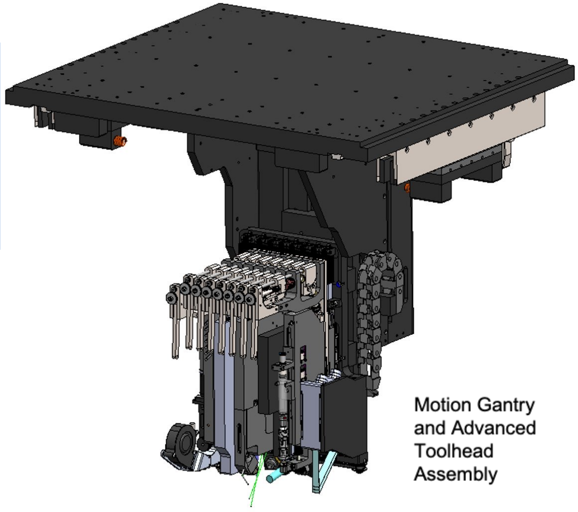
FY23 Accomplishments – Advanced Toolplate Development

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

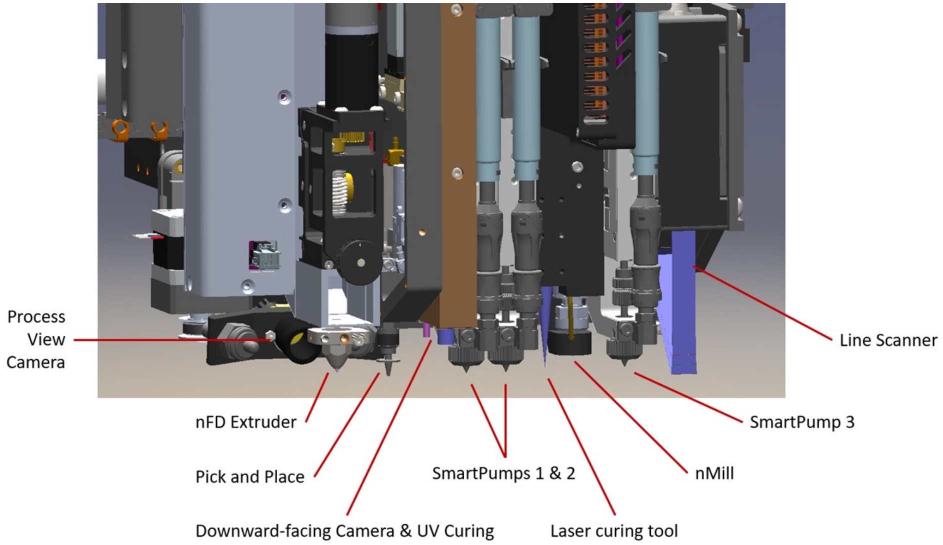
- The new Advanced Toolplate is 40% the volume of the previous Toolplate.
- Generation 3 tools are 35% smaller than generation 2, enabling a doubling in the number of tools on the Toolplate from four (4) to eight (8), thus doubling the ODME process capability and minimizing crew time in changeovers.

Target applications for infusion:

- Semiconductors / commercialization
- Microelectronics for future missions
- Sensors – HRP and ECLSS



- 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 wa scheduled for August but has been reschedule by the flight provider to October 2023. (Flight Opportunities Funded)
- New toolheads are also being developed for th Advanced Toolplate, including EHD inkjet (semiconductors) and Faraday electrodeposition (Phase II SBIR).



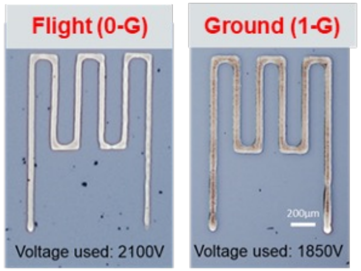
FY23 Accomplishments – Electrohydrodynamic Inkjet Development

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.)*

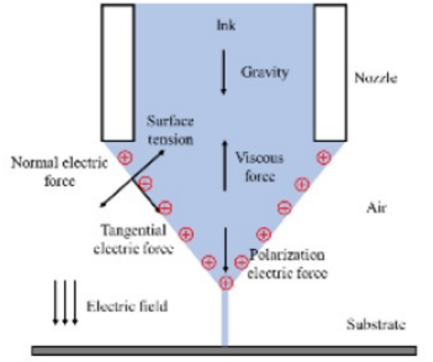
- EHD inkjet uses an electric field rather than piezoelectric force for very precise deposition. This system has the potential to advance thin film deposition SOA into the nanometer range.
- ODME and Flight Opportunities have already completed two parabolic flight campaigns (120 parabolas) of zero gravity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



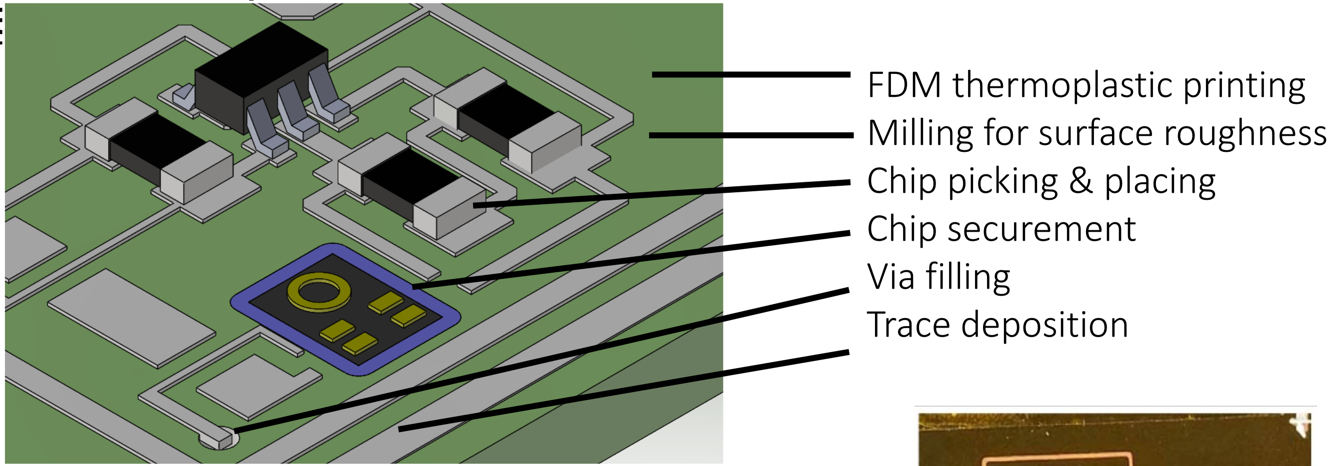
Line width 53 µm | Line width 62 µm



SPEC	DMP-2850 IJ (Industry Std)	EHD Inkjet
Minimum feature size	30 microns	0.5 microns
Ink viscosity	4-8 centipoise	0.1 - 500 centipoise
Ink surface tension	28-32 dynes/cm	1 - 800 dynes/cm
Droplet size	1pL - 10pL	0.1fL - 10pL

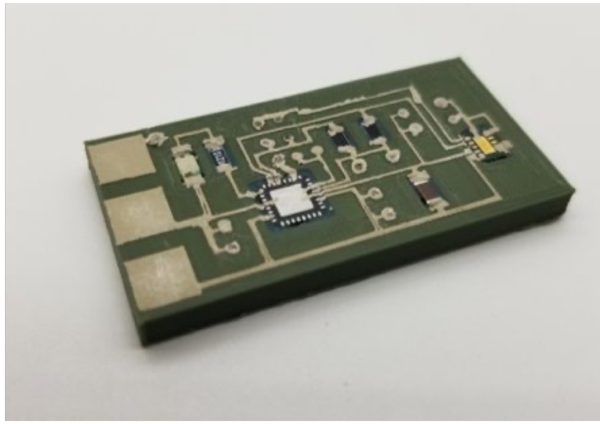
FY23 Accomplishments – Multilayer Process Development

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

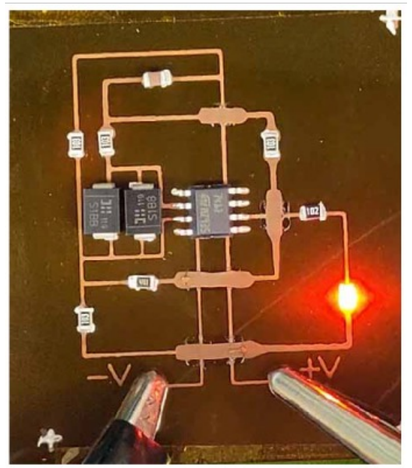


- Development and evaluation of multiple multilayer deposition processes and materials.
- Successful printing of a Multilayer flexible printed circuit board.
- Demonstrated with a functional LED blinking circuit board.
- ODME and Sciperio also developed and fabricated a functional multilayer CO_2 sensor.

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



Multilayer CO_2 sensor



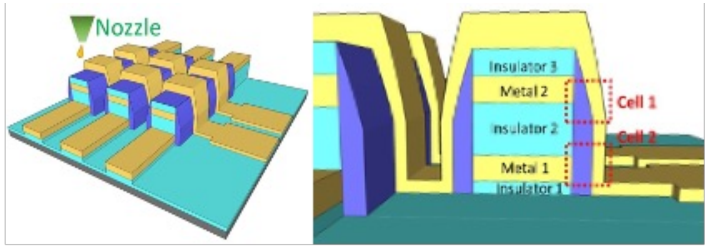
Multilayer functional blinking circuit

FY23 Accomplishments – Printed Semiconductor Development

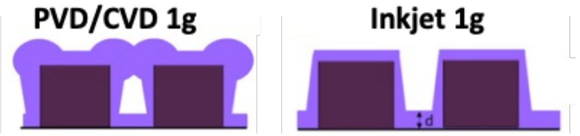
Tech maturation through ODME development is a critical phase of commercialization of printed semiconductors. ODME is collaborating with Intel, Axiom Space, TEL, Arizona State, and Univ. of Wisconsin to develop printed RERAM memory chips for microgravity production. *(ODME-funded research on labor and 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.

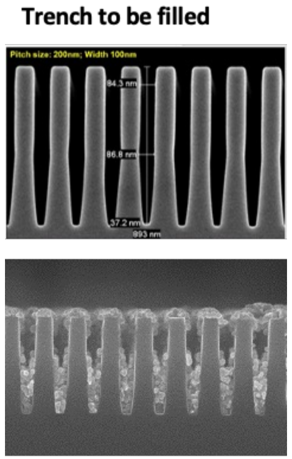
SEADS = Space Enabled Advanced Devices and Semiconductors



3-dimensional memory planned as demo printed electronic device for parabolic flights



- Combination of inkjet printing and µg offer high step coverage without voiding problem. Beneficial for 3D memory fabrication with high density and high performance



Target applications for infusion:
- Semiconductors / commercialization

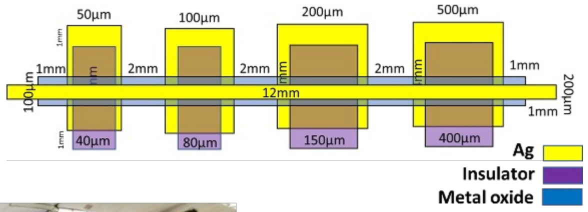
FY23 Accomplishments – Parabolic Flight Campaigns

<u>ODME has extensively used the Flight Opportunities suborbital parabolic flights program for validation of several newly developed technologies.</u> 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 – **<u>testing of new Advanced Toolplate</u> and tools**
- SEADS Semiconductors - **<u>testing of newly developed EHD inkjet process</u> for printing semiconductor memory chips (InSPA Funded)**
- EHD Inkjet Integration into Advanced Toolplate - **<u>testing of EHD inkjet head integrated into Advanced Toolplate</u>**

nScrypt Flight Printer with Adv Toolplate



SEADS parabolic test patterns

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

VALIDATION OF TECH DEVELOPMENT

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

ODME Project Assessment Summary

Project Name	Performance C	Performance S	Performance T	Performance P	Comments
Mid-Year	GREEN	GREEN	GREEN	GREEN	• **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 updaated 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**.
Annual	GREEN	GREEN	GREEN	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. <u>There may be risk going forward depending upon what path is chosen by GCD for ODME ISS orbital flight demonstration.</u> • **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**. <u>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.</u>

ODME Plans Forward and Transition / Infusion Plan

Infusion/transition plan

- 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.

Exploration & Science Applicability

- 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 Project Summary

FY23 Project Collaborations

- ODME collaborates between 9 NASA Centers, 14 public or private companies, and 20 different universities.

Publications and EPO

- 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.

Summary of the TechMat Capability End State for the Scope of the Project

- 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.