In-space Manufacturing (ISM): Pioneering Space Exploration

2015 Bay Area Maker Faire
ISM Objective: Develop and enable the manufacturing technologies and processes required to provide on-demand, sustainable operations for Exploration Missions. This includes development of the desired capabilities, as well as the required processes for the certification, characterization & verification that will enable these capabilities to become institutionalized via ground-based and ISS demonstrations.
In-space Manufacturing Path to Exploration

EARTH RELIANT

- 3D Print Tech Demo
- Additive Manufacturing Facility
- On-demand Utilization Catalogue
- Recycling Demo
- Printable Electronics Demo
- In-space Metals Demo

PROVING GROUND

International Space Station

- Space Launch System
- Commercial Cargo and Crew

Planetary Surfaces Platform
- Additive Construction Technologies
- Regolith Simulant Materials Development and Test
- Execution and Handling
- Synthetic Biology Collaboration

EARTH INDEPENDENT

Asteroids

Earth-Based Platform
- Certification & Inspection Process
- Material Characterization Database
- Additive Manufacturing Automation
- In-space Recycling Technology (SBIR)
- External In-space Manufacturing and Repair
### In-space Manufacturing Technology Development Roadmap

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**ISS Technology Demonstrations are Key in ‘Bridging’ Technology Development to Full Implementation of this Critical Exploration Technology.**
Step #1: First 3D Printer in Space!

- The 3D Print Tech Demo launched on SpaceX-4 (9/21/14) and was installed in the Microgravity Science Glovebox on ISS.
- To date, it has printed 21 parts in space (14 unique designs); the printer functioned nominally.
- First part “emailed” to Space: 3D Print of a ratchet tool demonstrated on-demand capability by uplinking a part file that was not pre-loaded to the 3D Printer.
- The first flight samples were received at NASA MSFC on 3/17/15.
- Results to be published late 2015.

Images courtesy of NASA.
3D Printer International Space Station Technology
Demonstration Status

Mechanical Property Test Articles

Functional Tools

Printer Performance Capability
In-Space Manufacturing Elements

◆ Material Characterization Database Development
  • Objective: Characterize microgravity effects on printed parts and resulting mechanical properties. Develop design-level database for microgravity applications.
  • MSFC team has performed initial characterization on ABS and ULTEM.
  • B-basis dataset received from RP+M for ULTEM through America Makes project.
  • MSFC will generate design property database from ground samples produced using the flight spare 3D printer.
  • Phase II operations for additional on-orbit prints of engineering test articles are being planned with ISS for later this year.
  • All datasets will be available through the MSFC Materials and Processes Technical Information System (MAPTIS).

◆ On-demand ISM Utilization Catalogue Development
  • Objective: Develop a catalogue of approved parts for in-space manufacturing and utilization.
  • Joint effort between MSFC AM materials and process experts and space system designers and JSC ISS Crew Tools Office.
  • Parts being considered include crew tools, payload components, medical tools, exercise equipment replacement parts, cubesat components, etc.
  • First parts are in design and ground test process.
AMF - Additive Manufacturing Facility (SBIR Phase II-Enhancement) with Made In Space

- Commercial printer for use on ISS
  - Incorporates lessons learned from 3D Printer ISS Tech Demo
  - Expanded materials capabilities: ABS, ULTEM, PEEK
  - Increased build volume
- Anticipated launch late CY2015

In-space Recycler ISS Technology Demonstration Development (SBIR 2014)

- Objective: Recycle 3D printed parts into feedstock to help close logistics loop.
- Phase I recycler developments completed by Made In Space and Tethers Unlimited.
- Phase II SBIR (2014) awarded to Tethers Unlimited.
- Final deliverable will result in flight hardware for the In-space Recycler for proposed ISS Technology Demonstration in FY2017.

Launch Packaging Recycling Phase I SBIR (2015)

- Objective: Recycle launch packaging materials into feedstock to help close logistics loop
In-Space Manufacturing Elements

◆ In-space Printable Electronics Technology Development
  - Development of inks, multi-materials deposition equipment, and processes
  - Collaborating with Xerox Palo Alto Research Center (PARC) on Printable Electronics technologies developed at MSFC and Xerox PARC.
  - NASA Ames Research Center developing plasma jet printable electronics capability
  - Jet Propulsion Lab (JPL) has Advanced Concepts project to develop “printable spacecraft”
  - Printable Electronics Roadmap developed targeting ISS technology demonstrations including RF sensors/antennae, in-space printed solar panel, and printable cubesats

◆ In-space Multi-Material Manufacturing Technology Development
  - In-space Adaptive Manufacturing (ISAM) project with Dynetics utilizing the Hyperbaric Pressure Laser Chemical Vapor Deposition (HP-LCVD)
  - HP-LCVD technology holds promise for a novel solution to manufacturing with multiple materials (including metallics) in microgravity.
  - Phase I deliverable is small spring similar to design utilized on ISS
Additive Construction by Mobile Emplacement (ACME)

- Joint initiative with the U. S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) Automated Construction of Expeditionary Structures (ACES) Project
- Objective: Develop a capability to print custom-designed expeditionary structures on-demand, in the field, using locally available materials and minimum number of personnel.
- Goal: Produce half-scale and full-scale structures with integrated additive construction system at a lab or planetary analog site (September 2017)

- Funded by NASA/GCDP and U.S. Army Corps of Engineers (USACE)
- Partnerships between MSFC, KSC, Contour Crafting Corporation (CCC), and the Pacific International Space Center for Exploration Systems (PISCES)
NASA In-Space Manufacturing Challenges

**Future Engineers Program**: National challenge conducted jointly by NASA and American Society of Mechanical Engineers (ASME)
- Competition was held in two divisions, Junior (K-12) and Teen (13-18)
- First Challenge was to design a tool that astronauts could use on ISS. Teen winner’s part will be printed on ISS later this year.
- The Space Container Challenge was announce on 5/12.
- Discussions underway for a joint NASA/IndyCar Challenge

**NASA GrabCAD Handrail Clamp Assembly Challenge**
- GrabCAD has a community of nearly 2 million designers
- Challenge was to design a 3D Printed version of the Handrail Clamp Assembly commonly used on ISS
- Nearly 500 entries in three weeks
- Five winners were selected
TEEN ENGINEERS
13-19 YEARS OLD

GRAND PRIZE:
Tour of the Space Shuttle Endeavor with an Astronaut in Los Angeles, CA

FOUR FINALIST PRIZES:
A One-Week Space Camp Scholarship

TEN SEMIFINALIST PRIZES:
A $50 3D Printing Gift Certificate

* 13-19 years old as May 12, 2015

WWW.FUTUREENGINEERS.ORG

JUNIOR ENGINEERS
5-12 YEARS OLD

GRAND PRIZE:
A 3D Printer For Your School

FOUR FINALIST PRIZES:
A One-Week Space Camp Scholarship

TEN SEMIFINALIST PRIZES:
A $50 3D Printing Gift Certificate

* 5-12 years old as May 12, 2015

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PROGRAM DATES

PROGRAM LAUNCH
12 MAY

ENTRIES CLOSE
02 AUGUST

TEN SEMIFINALISTS ANNOUNCED
02 SEPTEMBER

FOUR FINALISTS ANNOUNCED
16 SEPTEMBER

FINALIST INTERVIEW
30 SEPTEMBER

WINNERS ANNOUNCED
07 OCTOBER
In-space Manufacturing Summary

In order to provide meaningful impacts to Exploration Technology needs, the ISM Initiative Must Begin to Influence Exploration Systems Design Now.

- In-space Manufacturing offers:
  - Dramatic paradigm shift in the development and creation of space architectures
  - Efficiency gain and risk reduction for low Earth orbit and deep space exploration
  - “Pioneering” approach to maintenance, repair, and logistics will lead to sustainable, affordable supply chain model.

- In order to develop application-based capabilities in time to support NASA budget and schedule, ISM must be able to leverage the significant commercial developments.
  - Requires innovative, agile collaborative mechanisms (contracts, challenges, SBIR’s, etc.)
  - NASA-unique Investments to focus primarily on adapting the technologies & processes to the microgravity environment.

- We must do the foundational work – it is the critical path for taking these technologies from lab curiosities to institutionalized capabilities.
  - Characterize, Certify, Institutionalize, Design for AM

- Ideally, ISS US Lab rack or partial rack space should be identified for In-space Manufacturing utilization in order to continue technology development of a suite of capabilities required for exploration missions, as well as commercialization on ISS.
BACKUP
3D Printing in Zero-G Tech Demo Objectives

• The objective of the first phase of the technology demonstration is to confirm that Printer and Processes work in microgravity via printing of Test Articles & post-flight analyses.

• The objective of the second phase is to Demonstrate functionality of utilization parts such as crew tools and ancillary hardware.

• First parts printed returned on SPX-5 and will be sent to MSFC for detailed analyses and testing. All results will be published.
3D Printing in Zero-g Tech Demo Status

- To date, 21 parts have been printed of 14 unique objects. These included engineering test coupons, a microgravity test coupon, & utilization examples.

- Engineering Test Coupons:
  - Column: layer quality & tolerance
  - Tensile: mechanical characteristics
  - Compression: compressive strength
  - Flex: stiffness properties
  - Hole & Feature Resolution: geometric accuracy & tolerances for positive & negative range
  - Torque: torque strength

- Overhang Structure: would be difficult, if not impossible, to print in gravity w/out supports

- Utilization Examples:
  - Crowfoot Tool
  - Sample Container
  - Cubesat Clip
  - Ratchet (test of on-demand capability)