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

Commercial Cargo and Crew

Space Launch System

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

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

EARTH INDEPENDENT

Asteroids
## In-space Manufacturing Technology Development Roadmap

**Earth-based** | **International Space Station** | **Exploration**
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**Ground & Parabolic centric:**
- Multiple FDM Zero-G parabolic flights
- Trade/System Studies for Metals
- Ground-based Printable Electronics/Spacecraft
- Verification & Certification Processes under development
- Materials Database
- Cubesat Design & Development

**ISS:**
- 3D Print Tech Demo
- Future Engineer Challenge
- Utilization Catalogue
- ISM Verification & Cert Process Development
- Add. Mfctr. Facility (AMF)
- In-space Recycler SBIR
- In-space Material Database
- External In-space 3D Printing
- Autonomous Processes
- Additive In-space Repair

**Focus**
- In-space Recycler Demo
- Integrated Facility Systems for stronger types of extrusion materials for multiple uses including metals & various plastics
- Product: Ability to produce multiple spares, parts, tools, etc. “living off the land”
- Autonomous final milling to specification

**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.
In Space Manufacturing Technology Infusion

◆ 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

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

WWW.FUTUREENGINEERS.ORG

PROGRAM DATES

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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
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)