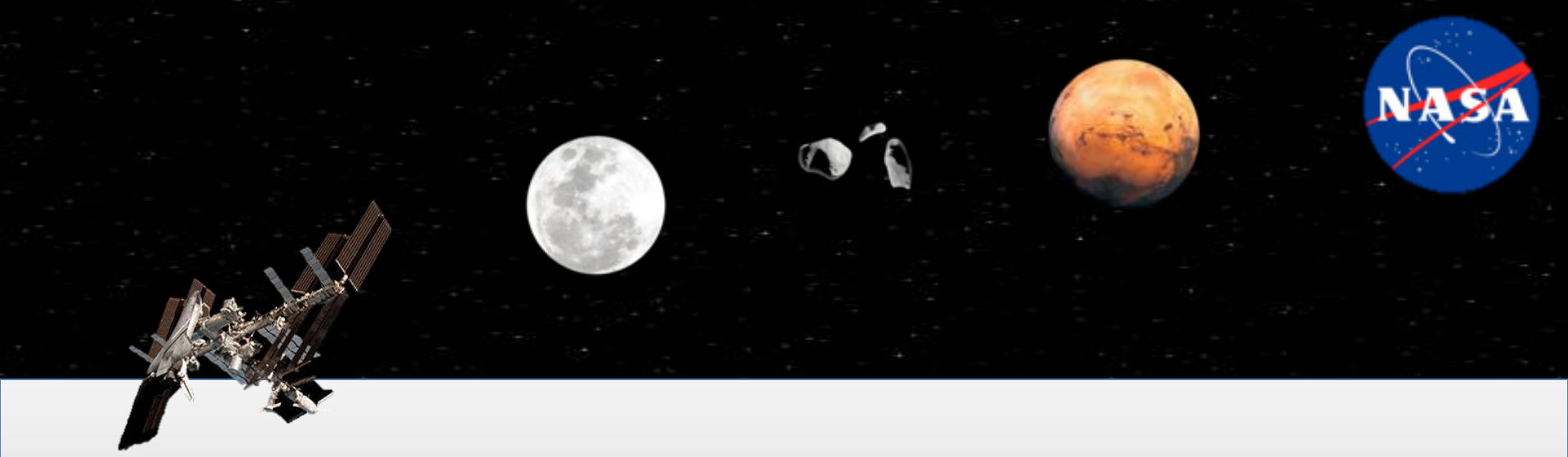

In-space Manufacturing: Make it, Don't Take it!

G.I.R.L 2017
October 7, 2017

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What I thought I would get....

What I actually got

The Future is NOW!

Apollo Guidance Computer

- 1200 Transistors
- 70 lbs
- 4K Memory
- 1 MHz processor
- $150K

iPhone 6.0

- 2 Billion Transistors
- 4.5 ounces
- 128 Gb Memory
- 1.4 GHz processor
- $399

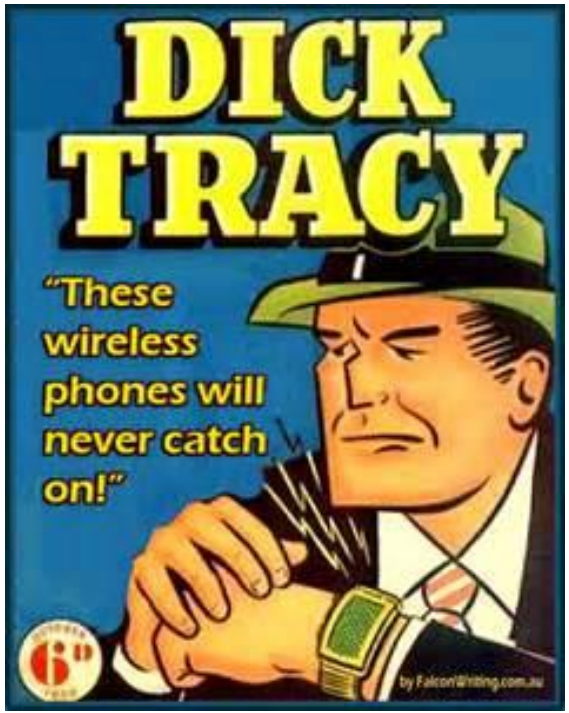
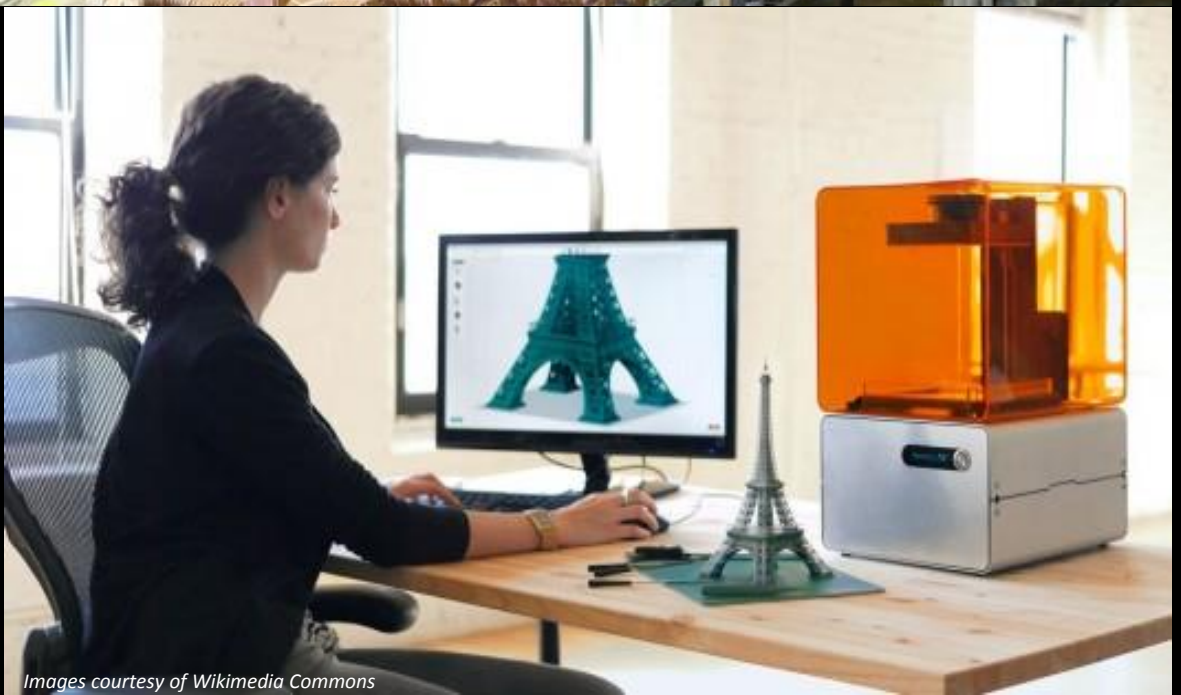


Image courtesy of Wikimedia Commons

Printing Press

Image courtesy of Creative Commons

3D Printing, i.e. Additive Manufacturing



Images courtesy of Wikimedia Commons

Large Facilities

Mass Production

Time

Big Workforce

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Independence

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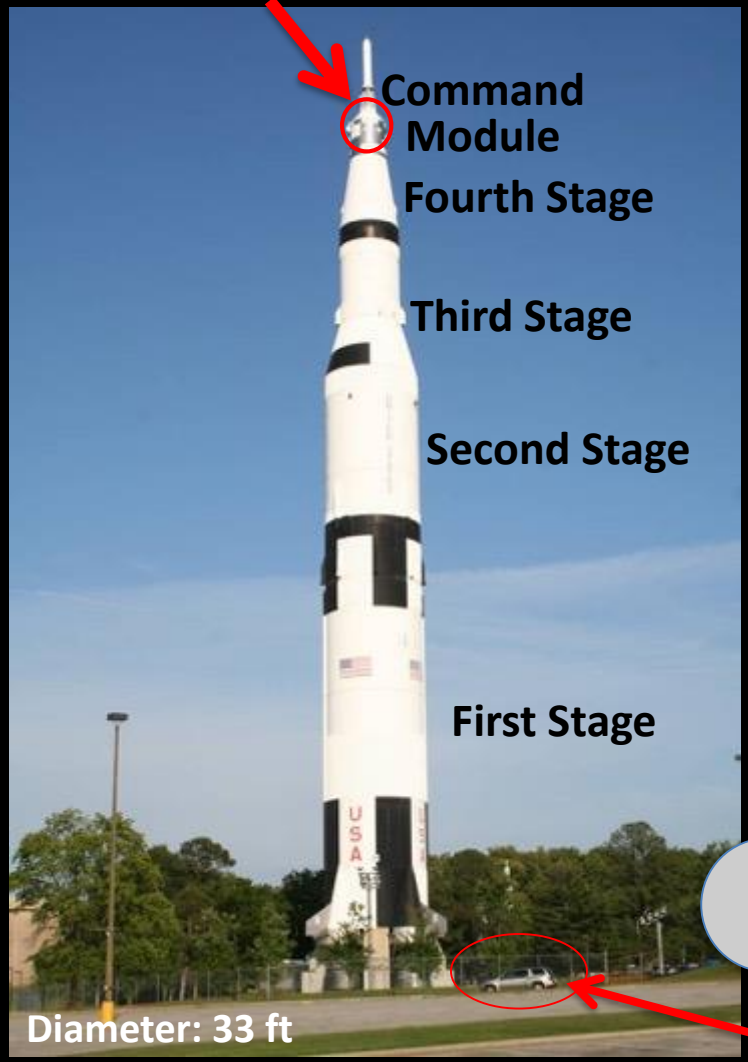
Saturn V – MASSive Perspective

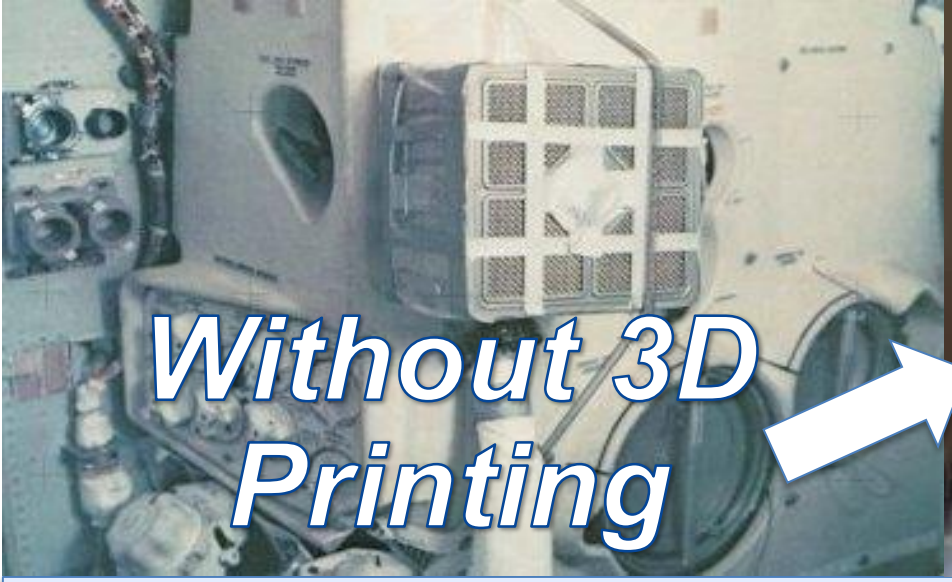
What Was Returned



SATURN V

- 6.6M lbs sat on the launch pad.
- But only 12.8K lbs came back.
- This is equivalent to taking a road trip in a car and coming back with just the left front wheel's lug nuts!

Image courtesy of NASA



Square peg in Round Hole? No problem!

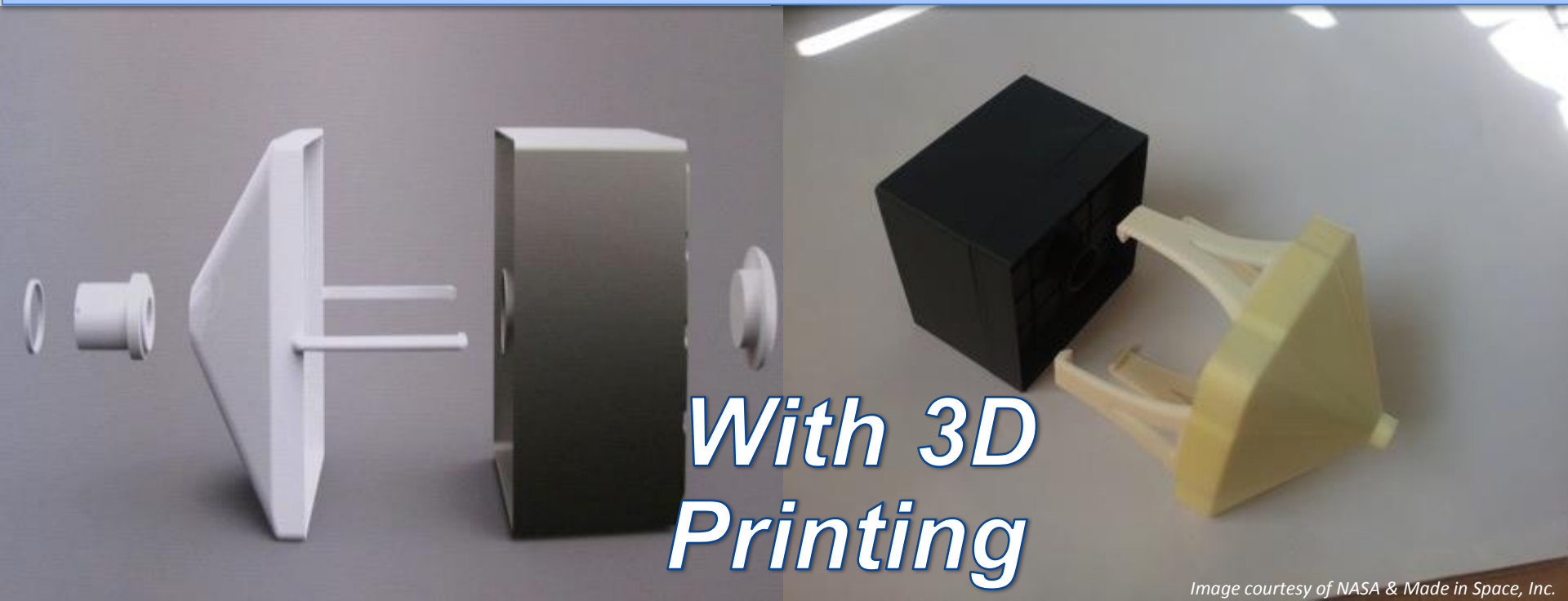
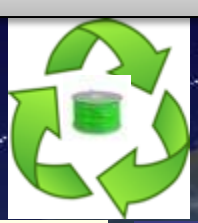


Image courtesy of NASA & Made in Space, Inc.

What is In-space Manufacturing (ISM)?

- ISM is responsible for developing the on-demand manufacturing capabilities required for sustainable Exploration Missions to destinations such as Mars. This includes advancing the needed technologies, as well as establishing the skills & processes that will enable the technologies to go from novel to institutionalized.
- These technologies are evolving rapidly due to terrestrial markets. NASA is leveraging this commercial development by adapting them for the space environment in order to develop these capabilities within a realistic timeframe and budget.
- ISM utilizes the International Space Station (ISS) as a critical microgravity test-bed to adapt these technologies for microgravity operations and evolve the current operations mindset from earth-reliant to earth-independent.

TECHNOLOGIES





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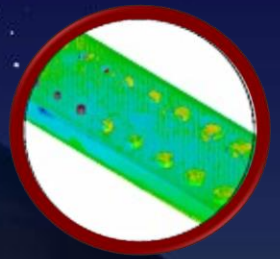
SKILLS & PROCESSES

Design Optimize

Characterize

Certify



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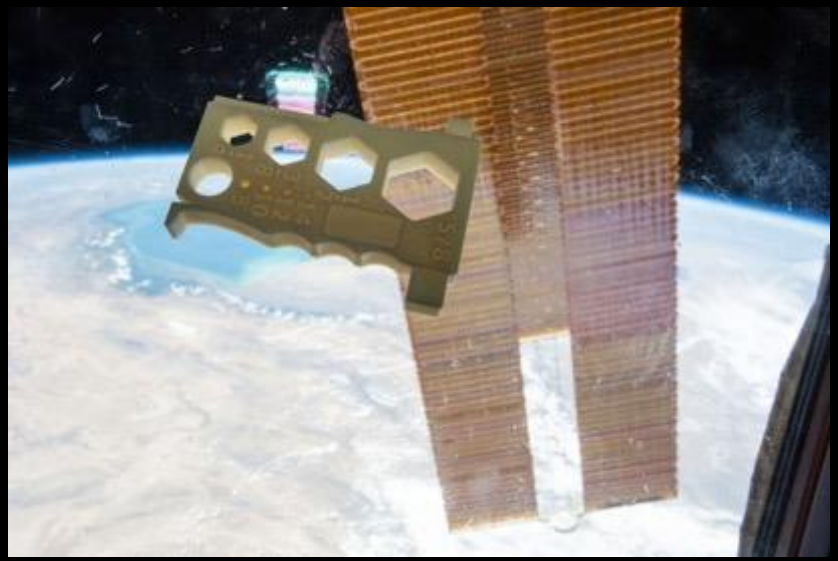
On-demand Manufacturing Capability for Exploration Missions

Step #1: First 3D Printer in Space!

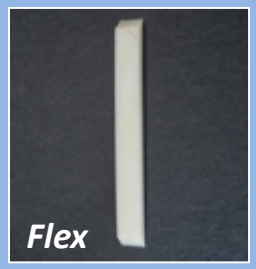
- The first 3D Printer was launched to ISS on SpaceX-4 in September 2014. The printer was designed and built by Made in Space, Inc. under NASA Small Business Innovation Research contract.
- The primary objective of this printer is to compare print quality and performance between the flight and ground samples.
- To date, 45 parts have been printed in space including the first-student designed part to be printed in space!
- The first flight samples have underwent test & analyses to compare to ground control samples. We are currently printing more parts on ISS now!

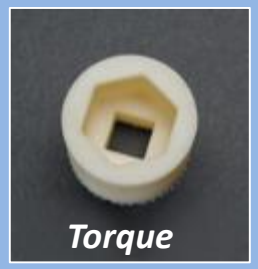


Images courtesy of NASA

3D Print Tech Demo Parts Printed

Mechanical Property Test Articles





Functional Tools

Printer Performance Capability

First Part "Emailed" to Space!

Design Part

Uplink to ISS

Manufacture on ISS

3D Printed Wrench: Demonstrated on-demand manufacturing capability by uplinking a part file that was not pre-loaded to the 3D Printer.

You can print the same wrench by downloading the file at NASA 3D Resources!

Images courtesy of NASA & MIS, Inc.

Additive Manufacturing Facility (AMF): Commercial ISS 3D Printer

- The second 3D Printer, the Additive Manufacturing Facility (AMF), is now operating on ISS.
- This printer is owned and operated by Made in Space, Inc. thru agreement with the ISS National Lab and Center for Advancement of Science in Space (CASIS).
- NASA is one of the customers, as well as other government agencies, industry, and academia.
- AMF can print with ABS, Ultem and High-density Polyethylene.

MADE IN SPACE
madeinspace.us

ISS
U.S. NATIONAL LABORATORY

NASA CASIS
POWERED THROUGH PARTNERSHIP

The Capability to Manufacture Items in Space is a Critical Enabler for the Path to Mars

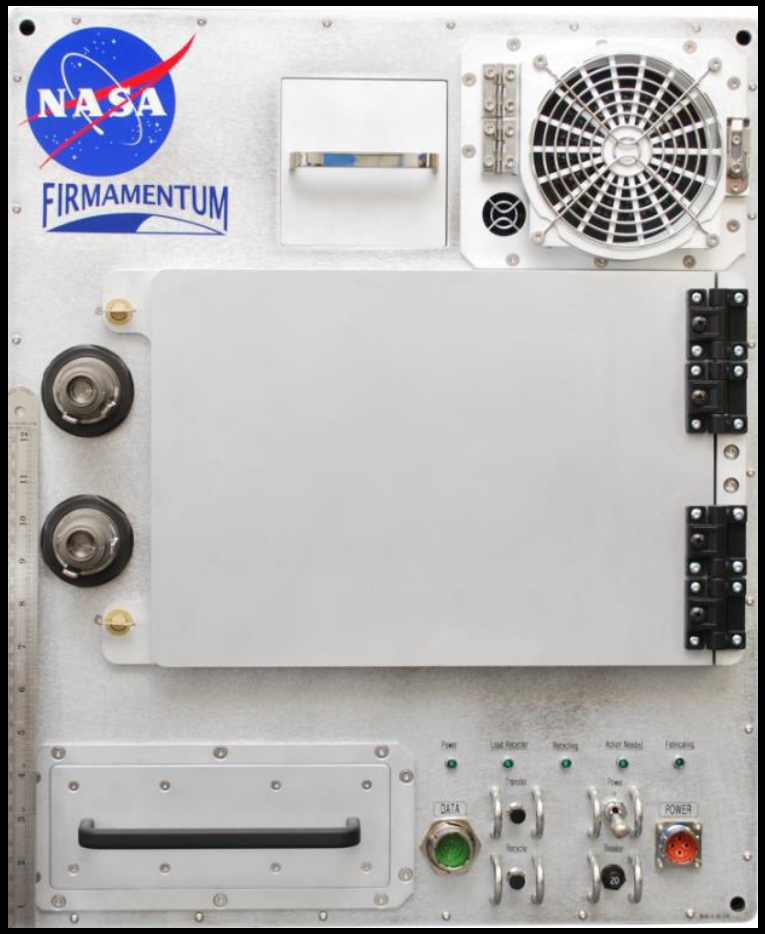
NASA Article Ranks "Understanding how to manufacture items in space" as the #1 was that ISS is helping us on our journey to Mars!!!

1. **Understanding how to manufacture items in space (3-D Printing)**

"As crews head to Mars, there may be items that are unanticipated or that break during the mission. Having the ability to manufacture new objects on demand while in space will greatly benefit missions. The 3-D Printing in Zero-G Technology Demonstration validates that a 3-D printer works normally in space. This is the first step towards establishing an on-demand machine shop in space, which is a critical enabling component for crewed missions to deep space."

Refabricator Space Station Technology Demonstration

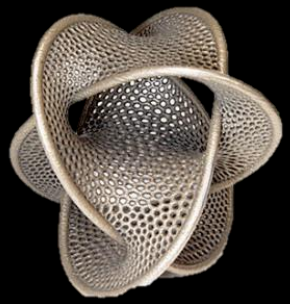
- The Refabricator is the first integrated 3D Printer and Recycler that will be operated on the International Space Station.
- You can put a 3D Printed part in and it will recycle it back into new ‘feedstock’ to make new and/or different parts.
- It was developed by Tethers Unlimited, Inc. though Small Business Innovation Research (SBIR) awards.
- This technology also has exciting potential for use right here on earth!!

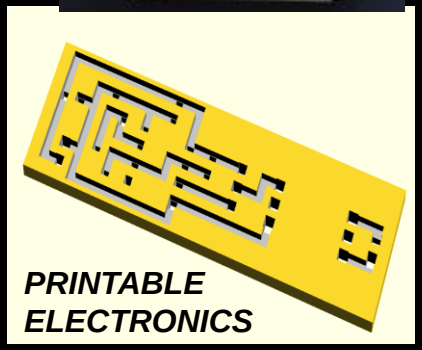


In-space Manufacturing Technology Development Areas

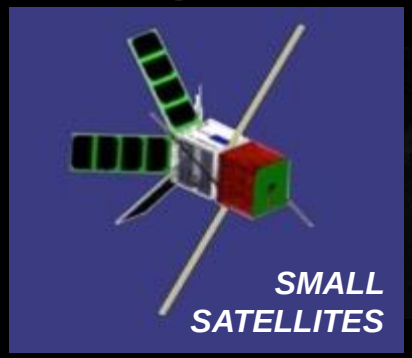
IN-SPACE RECYCLER

MULTI-MATERIALS



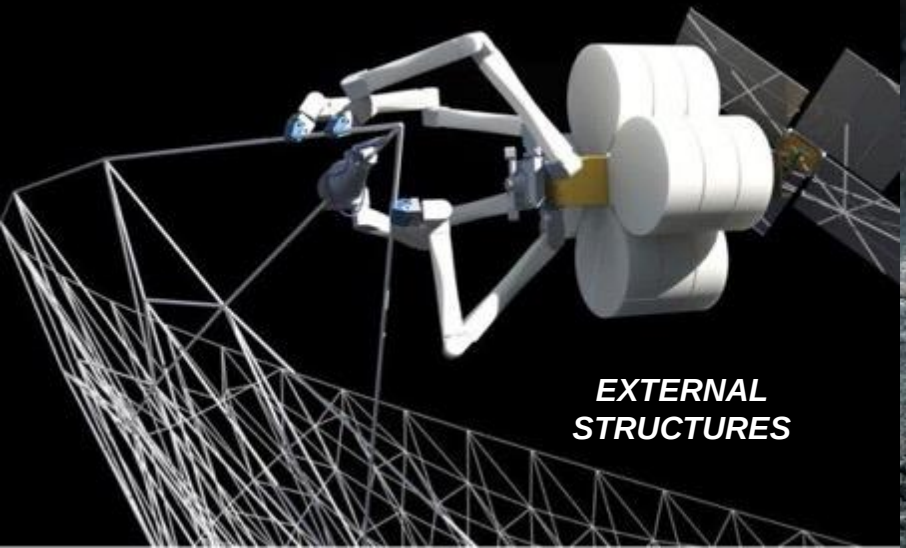


PRINTABLE ELECTRONICS



SMALL SATELLITES

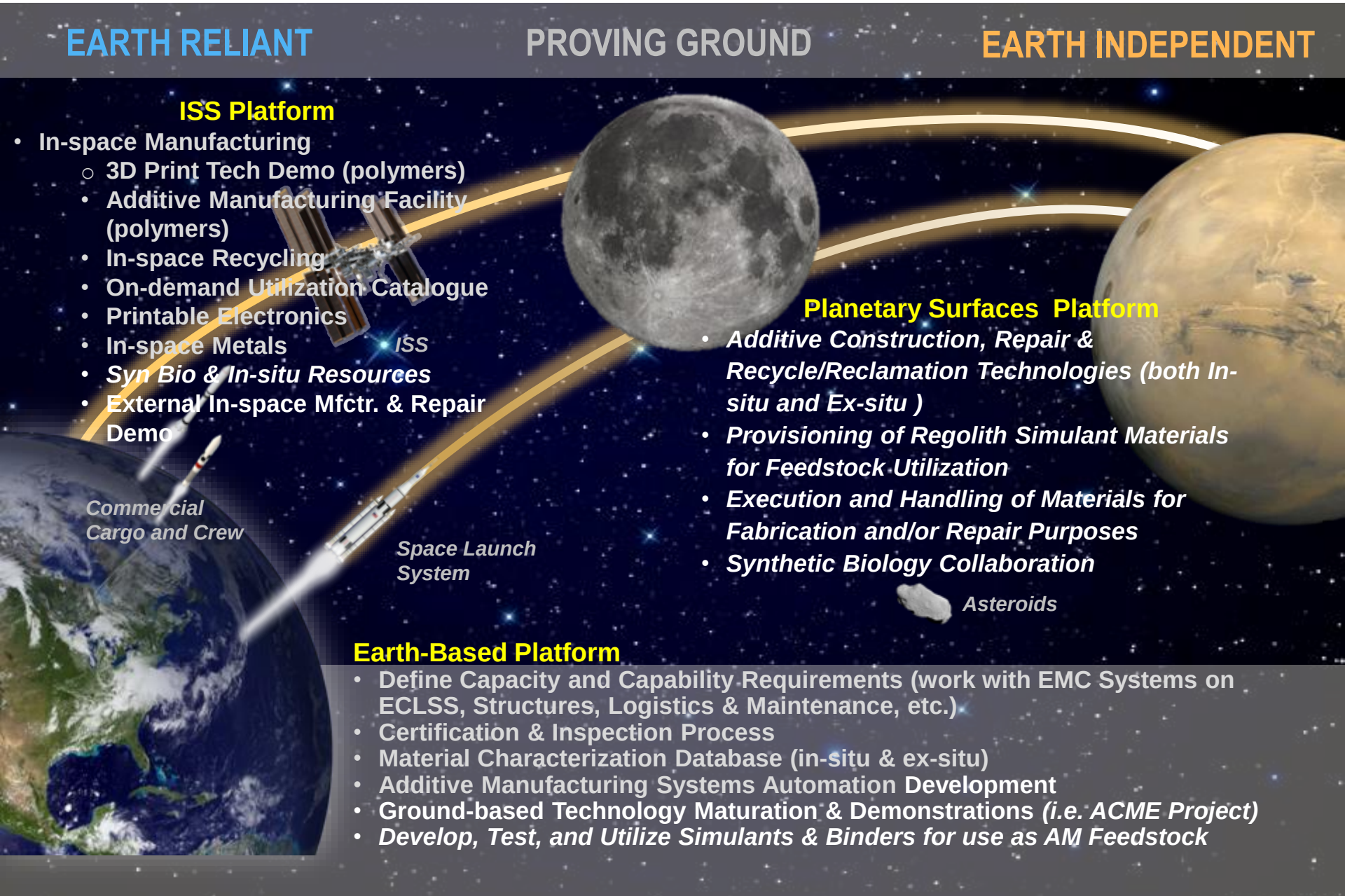
ADDITIVE CONSTRUCTION OF LARGE STRUCTURES USING IN-SITU RESOURCES



EXTERNAL STRUCTURES

Images courtesy of NASA

In-Space Manufacturing (ISM) Path to Exploration



In-Space Manufacturing (ISM)
Phased Technology Development Roadmap

Earth-based

Pre-2012

***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

Demos: Ground & ISS

3D Print
Plastic Printing Demo

Mat. Char.

Recycler
Mat. Char. ***Utilization Testing***
AMF

Metal Printing
Fab Lab
External Mfctr. ***Self-repair/ replicate***

2014

- In-space:3D Print: First Plastic Printer on ISS Tech Demo
- NIAC Contour Crafting
- NIAC Printable Spacecraft
- Small Sat in a Day
- AF/NASA Space-based Additive NRC Study
- ISRU Phase II SBIRs
- Ionic Liquids
- Printable Electronics

2015 - 2017

- ***3D Print Demo***
- ***Add. Mfctr. Facility (AMF)***
- ***ISM Cert Process Part Catalogue***
- ***ISS & Exploration Material & Design Database***
- ***External Manufacturing***
- ***Autonomous Processes***
- ***Future Engineers***
- ***Additive Construction***

2018 - 2024

ISS: Multi-material "Fab Lab" Rack Test Bed *(Key springboard for Exploration 'proving ground')*

- **Integrated Facility Systems for stronger types of extrusion materials for multiple uses including metals & various plastics, embedded electronics, autonomous inspection & part removal, etc.**
- **In-space Recycler Demo**
- ***ACME Ground Demos***

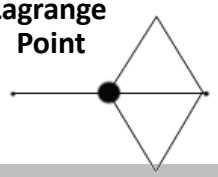
Exploration Missions

Asteroids

Cislunar

Mars

Lagrange Point



2025-35+

Cislunar, Lagrange FabLabs

- Initial Robotic/Remote Missions
- ***Provision feedstock***
- ***Evolve to utilizing in situ materials (natural resources, synthetic biology)***
- ***Product: Ability to produce, repair, and recycle parts & structures on demand; i.e.. "living off the land"***
- Autonomous final milling

Planetary Surfaces Points Fab

- Transport vehicle and sites would need Fab capability
- ***Additive Construction & Repair of large structures***

Mars Multi-Material Fab Lab

- ***Provision & Utilize in situ resources for feedstock***
- ***FabLab: Provides on-demand manufacturing of structures, electronics, & parts utilizing in-situ and ex-situ (renewable) resources.*** Includes ability to inspect, recycle/reclaim, and post-process as needed autonomously to ultimately provide self-sustainment at remote destinations.

ISS Serves as a Key Exploration Test-bed for the Required Technology Maturation & Demonstrations

AN EDUCATION PROGRAM FOR TOMORROWS INNOVATORS

www.futureengineers.org

Future Engineers is an education platform that hosts and develops design challenges for young innovators. We are delighted to host the 3D Printing in Space Challenges powered by the ASME Foundation. On September 21st, NASA launched the first-ever Zero-G 3D Printer (built by Made In Space) to the International Space Station aboard SpaceX-4. To celebrate the launch of this 'In Space Manufacturing' revolution, the American Society of Mechanical Engineers (ASME) Foundation and NASA partnered together to develop a series of 3D Space Challenges focused on solving real-world space exploration problems. Students can submit 3D models directly to the site for a chance to win out-of-this-world prizes!

Summary

In order to provide meaningful capability for on-demand manufacturing during Exploration missions, ISM must continue to test these technologies on the ISS and 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 terrestrial developments.**
  - Requires innovative, agile collaboration with industry and academia.
  - NASA-unique Investments to focus primarily on developing the skillsets and processes required and adapting the technologies to the microgravity environment & operations.
- **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
- **Ultimately, ISM will utilize an ISS US Lab rack to develop an integrated "Fab Lab" with the capability to manufacture and recycle multi-material components, including the capability for electronics, as well as automation of part inspection and removal.**

In-Space Manufacturing (ISM)

"If what you're doing is not seen by some people as science fiction, it's probably not transformative enough."

-Sergey Brin

Now for my favorite part…Q&A!!