Out of Earth Manufacturing
Context and Recent Advancements

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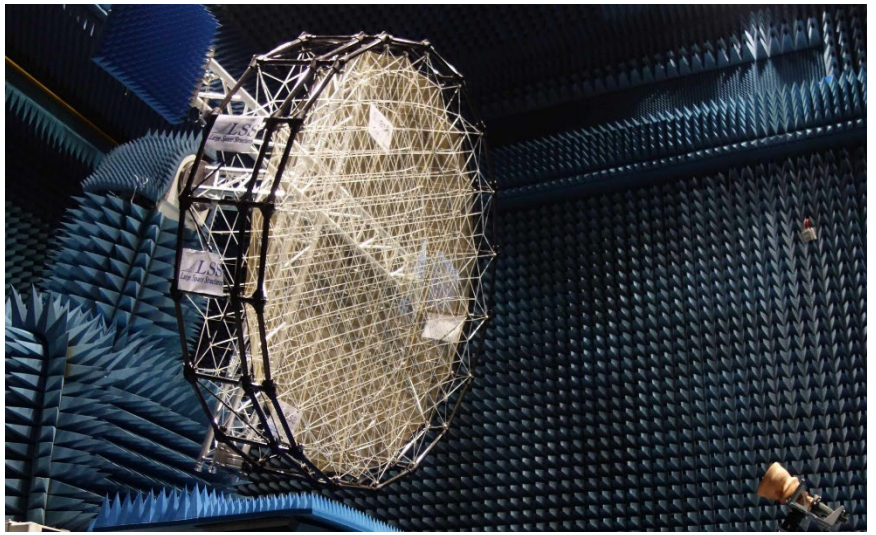
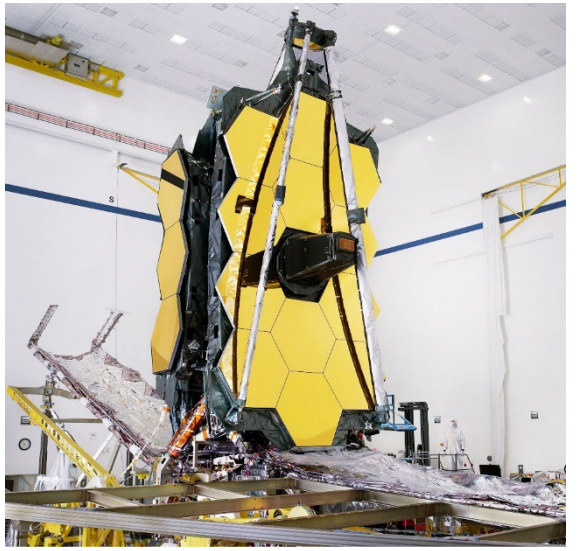
Space for Inspiration 13/07/2022

Manufacturing in Space: what for?

Current Model

- Design and manufacturing of spacecraft on ground for launch
  - Launcher fairing **size limitation** ⇒ Spacecraft structure (e.g. solar array, antennae) size limitation ⇒ **performance ceiling**
  - Design to resist launch loads ⇒ i.e. added mass, long qualification
  - Long **time to market**
- Alternative: deployables ☞ Complexity, **long lead time**





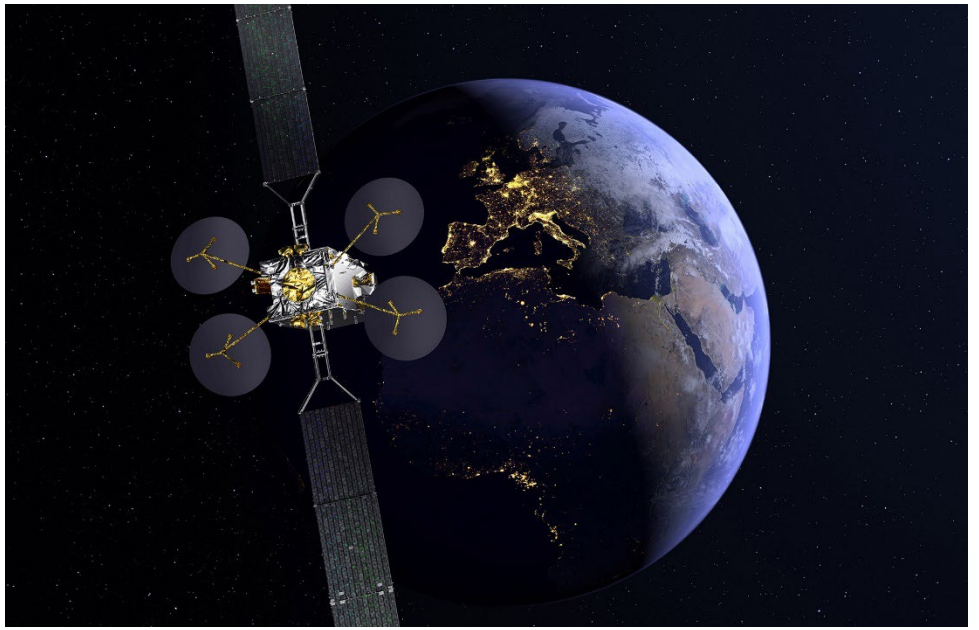
Manufacturing in Space: what for?
Current Model

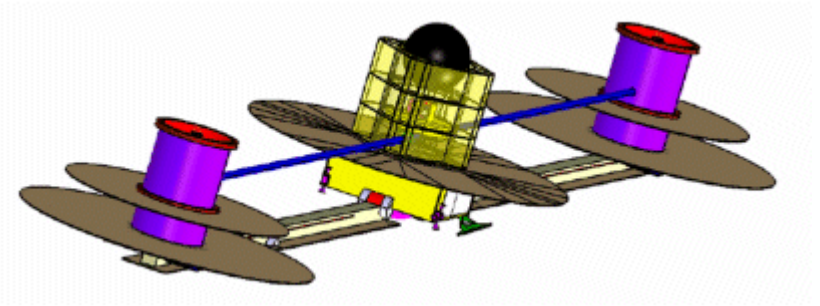
•Supplies for human exploration missions are provided from Earth, as redundancy payload or through regular cargo missions:

- •Significant amount of **supplies not used** (in addition to packaging etc…)
- •**Launch costs** associated to cargo missions
- •Not practical for future missions to **remote destinations** (e.g. Mars)

What for?
New Paradigm: On-Orbit Manufacturing, Assembly and Recycling

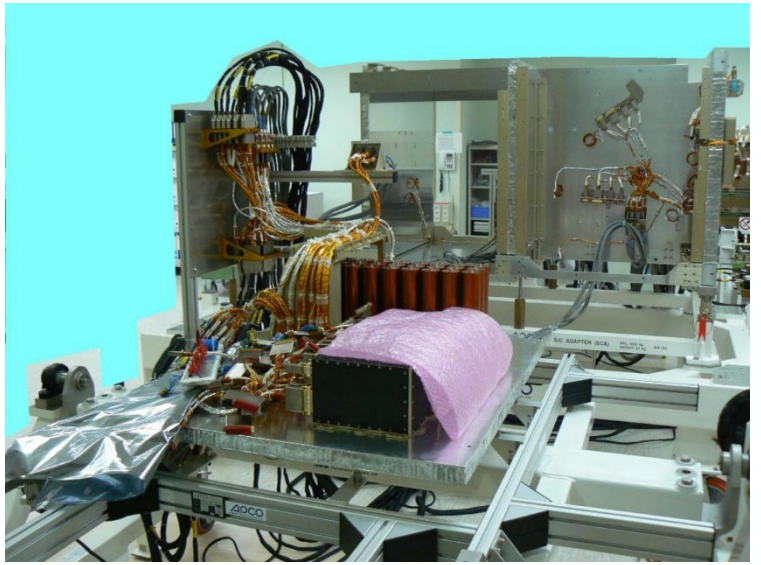
- Larger structures (no fairing size limitation): e.g.
  - Solar arrays ☞ higher power and **higher payload capacity** for a given class of satellites, **higher performance-to-launch-cost**, alternative to A-train
  - Antennae reflectors ☞ narrower emitted beam, higher gain, **higher data throughput** for telecommunications
  - Large aperture Telescope, large Interferometer ☞ **higher science return**



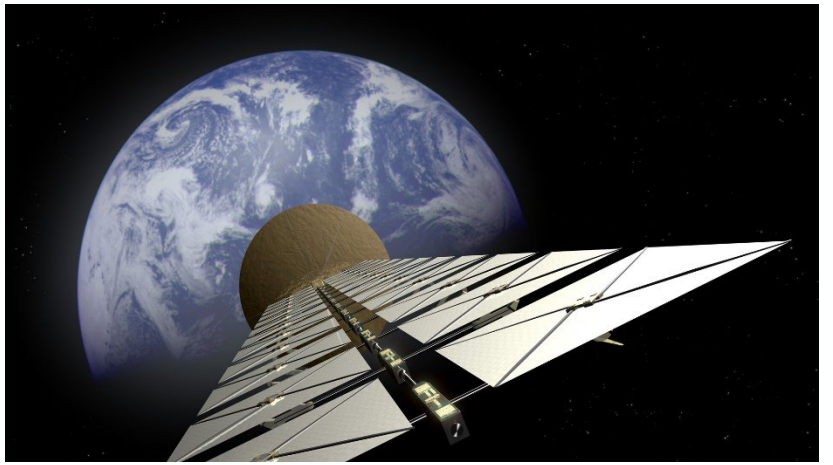


What for?
New Paradigm: On-Orbit Manufacturing, Assembly and Recycling

- Spacecraft on-orbit refurbishment and upgrade enabled ⇒ **life extension**, cost savings compared to launching new assets
- Longer term: leasing of assets (e.g. reflectors), decoupled payload and platform ⇒ payload update on orbiting platforms; platforms leasing



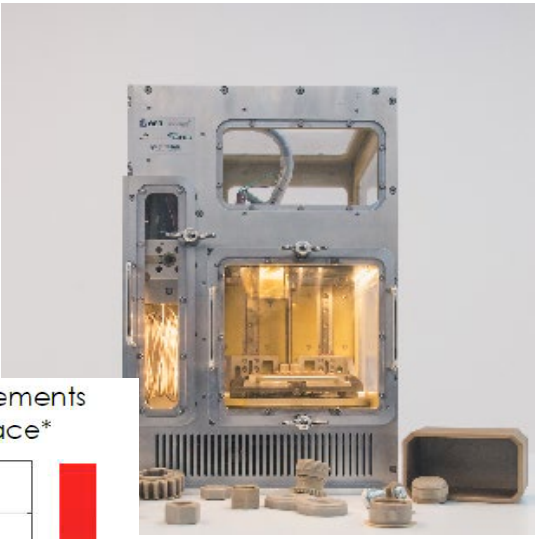
- Long term: manufacturing and maintenance of very large structures (e.g. space-based solar power)

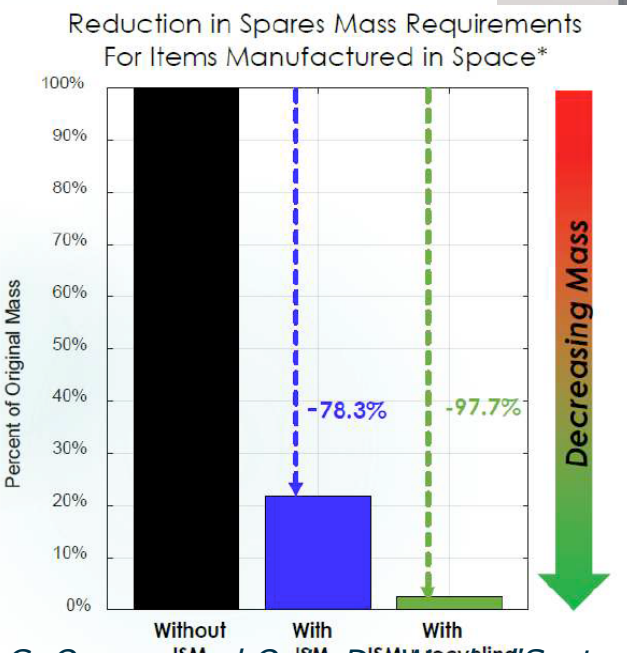


- Benefits **applicable to a wide range of missions** for Telecom, Earth Observation, Navigation, Science, Exploration

What for?
New Paradigm: On-Orbit Manufacturing, Assembly and Recycling

- On-demand manufacturing and recycling of spare parts, tools during long term human exploration missions ⇒ **simplified maintenance logistics** ⇒ savings in resupply missions and materials
- In-situ manufacturing and assembly e.g. of cubesats ☞ **flexibility** and redundancy in mission planning



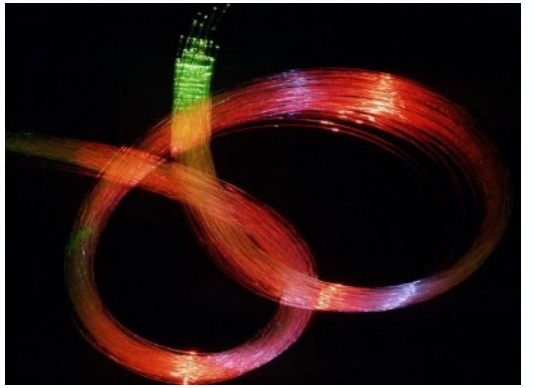


Adapted from A. C. Owens, and O. L. De Weck. "Systems Analysis of In-Space Manufacturing Applications for the International Space Station and the Evolvable Mars Campaign", AIAA SPACE 2016. 2016. 5394

What for?
New Paradigm: On-Orbit Manufacturing, Assembly and Recycling

•In-situ construction of infrastructure, in-situ propellant production and in-situ manufacturing of hardware (e.g. tools) for human exploration to the lunar (and Martian) surface ☞ enabling capabilities for **sustainable** surface exploration, longer term **commercial activities**

•**Use of space conditions** for production of materials with enhanced properties (i.e. without defects associated to terrestrial conditions) for **commercialization** on Earth



Manufacturing in Space: what for?
What is coming

Credit: https://www.flickr.com/photos/195131646@N04/51912424446

Credit: SpaceX

Credit: ESA

- Significant delivery capability to LEO, Moon

⇒ Expected increase in number of space assets on orbit, on the Moon

☞ Need for

Space Sustainability!

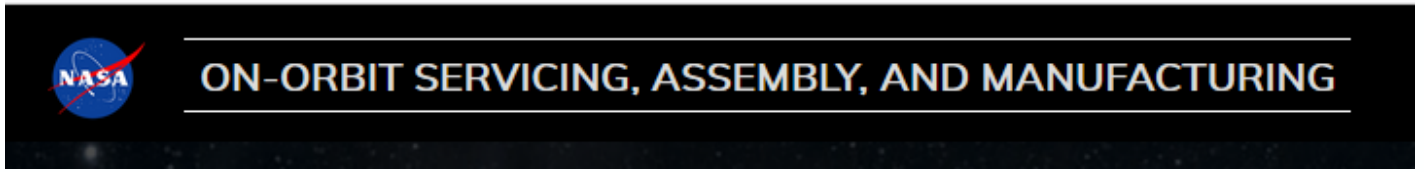
- Manufacturing in Space

☞ Longer term: recycling of end-of-life spacecraft structures and orbital debris

What are we doing about it?

- Several initiatives ongoing internationally

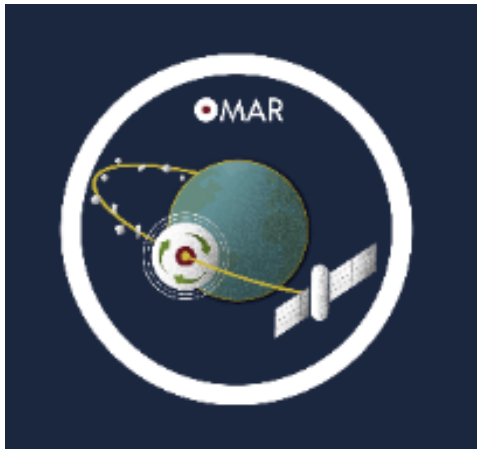
NASA In-space Manufacturing Project 2014



NASA OSAM

DARPA NOMAD 2021

ESA Out of Earth Manufacturing



ESA OMAR

China CAST

What are we doing about it?

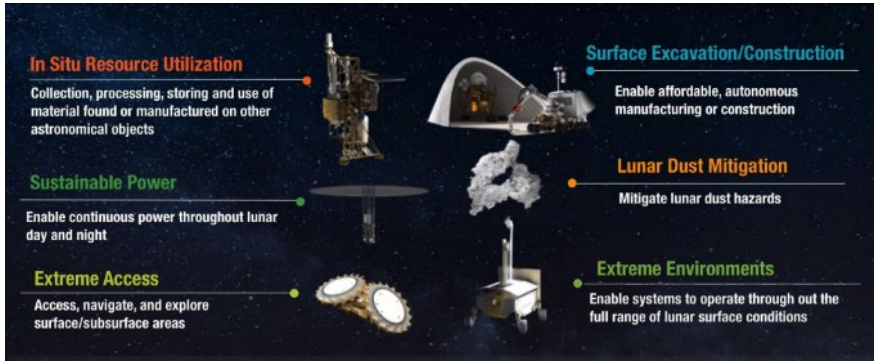
- Several initiatives ongoing internationally

CATAPULT Satellite Applications

UK

PERIOD
PERASPERA In-Orbit Demonstration

EU PERIOD

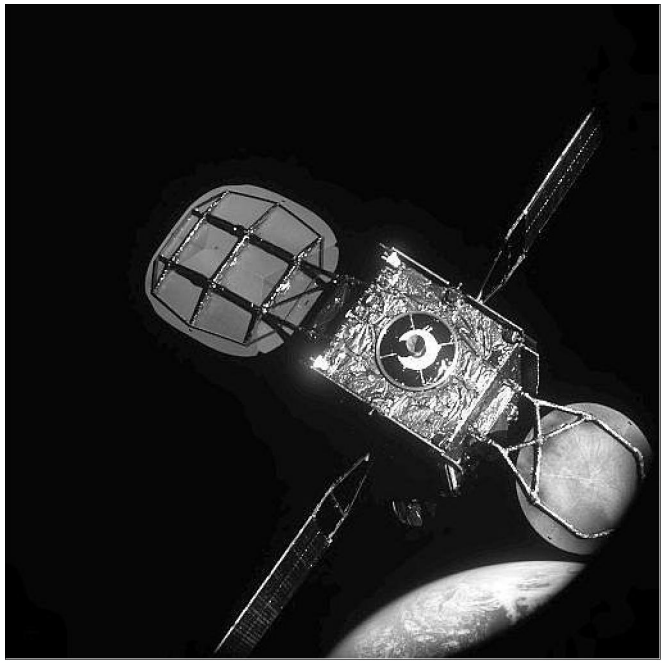


NASA Lunar Surface Innovation Initiative

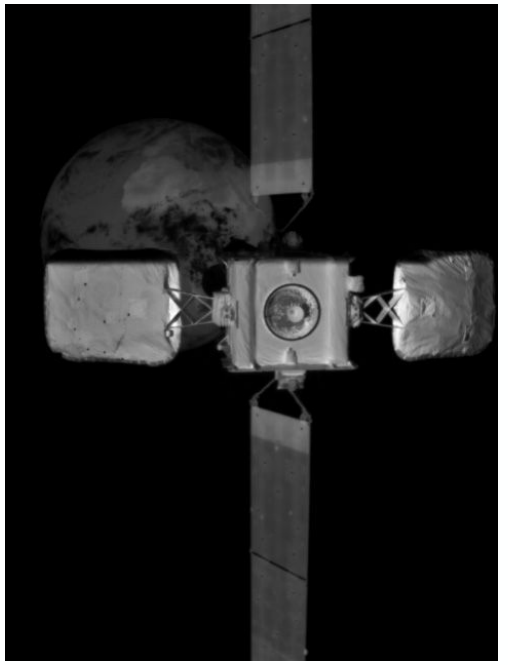
Luxembourg ESRIC

What we can (already) do: In orbit Servicing

- First commercial in-orbit services are **now a reality**
  - ☞ MEV-1 (Mission Extension Vehicle-1) docked to GEO telecommunications satellite Intelsat 901 in February 2020, to provide 5 year life extension
  - ☞ MEV-2 docked with Intelsat 10-02 in April 2021 for a 5 year life extension mission



IS-901 satellite from MEV-1, which successfully docked with Intelsat 901 satellite on the 25 February 2020 (image credit: Northrop Grumman)



Coseup view of the IS-10-02 satellite, captured by the MEV-2 vehicle as it approached to dock. (Image credit: Northrop Grumman)

What we can (already) do: Polymer and composite manufacturing limited size

POP 3D

09/2015 – 03/2016

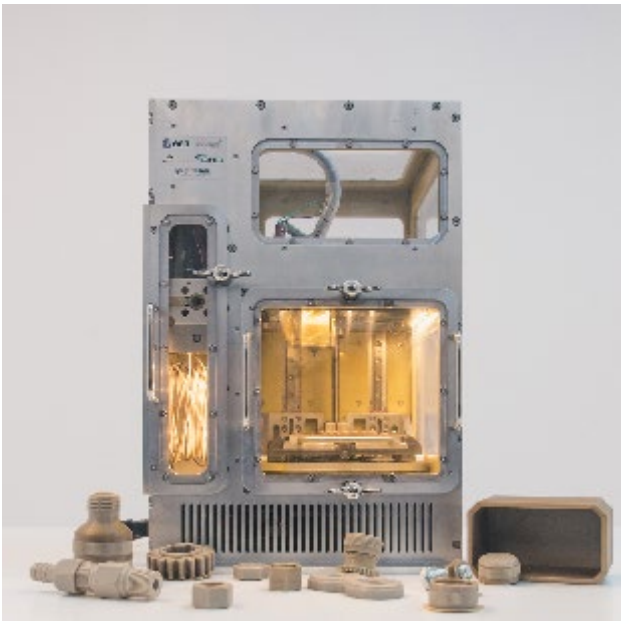
- Demonstrator in ISS
- 1 Print
- Post analysis

PLA

FLIGHT

MELT

TRP 09/2015 – 03/2018



- Demonstration of polymer AM **independent of gravity vector**

PEEK

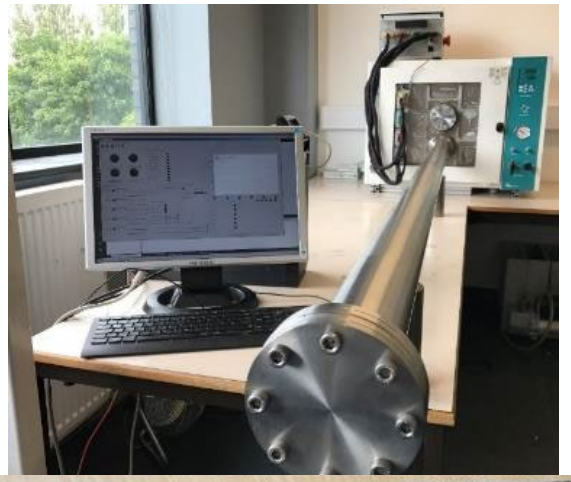
Ground Demo

Composite and Polymer Manufacturing Unlimited Size

IOM Very Long Boom

GSTP 12/2015 – 05/2017

MAGNAPARVA™ esa



- Demonstration of pultrusion of **composite booms** in vacuum

Epoxy – Carbon Fabric

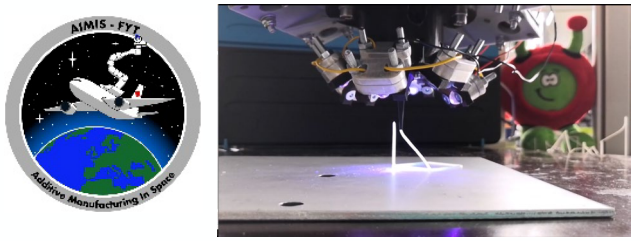
Ground Demo

AIMIS

11/2019 – to date

HM Hochschule München University of Applied Sciences

esa



- Fly Your Thesis campaign
- **3D Printer prototype using UV curing suitable for µG**
- Straight, curved and connected rods
- Start/stop and free floating

Photo-reactive Resin

PARABOLIC FLIGHT

IMPERIAL

TRP 01/2019 – to date

AIT BEEVERYCREATIVE esa

OHB AZIMUT SPACE

- **3D Printer** with **unlimited dimension** in one direction
- **Large parts** production
- Designed to meets **ISS operational** requirements (EDR2 rack)

Engineering Polymers

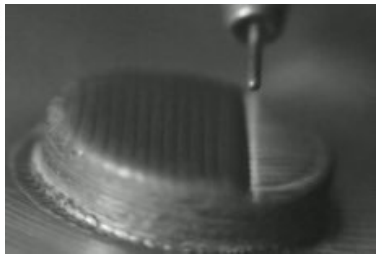
Ground Demo

What we cannot yet do (but is on the way)
Metal manufacturing on orbit

METAL3D

2017 – to date

AIRBUS esa



- Co-funded technology demonstrator
- **First demo of metal AM on orbit**
- Experiment insert on EDR2
- Intended for small and complex parts

Stainless Steel

FLIGHT IN 2023

On the way: subsystem manufacturing

- ESA Clean Space OMAR study

AIRBUS