Additive and Advanced Manufacturing for Space Technology

Mikko Nikulainen

Head of the Components Technology and Space Materials Division

Contact Details: mikko.nikulainen@esa.int / tommaso.ghidini@esa.int

AM: Enabling Technology for Future Space Missions

Enabling Industry to maximise benefits of the technology requires:

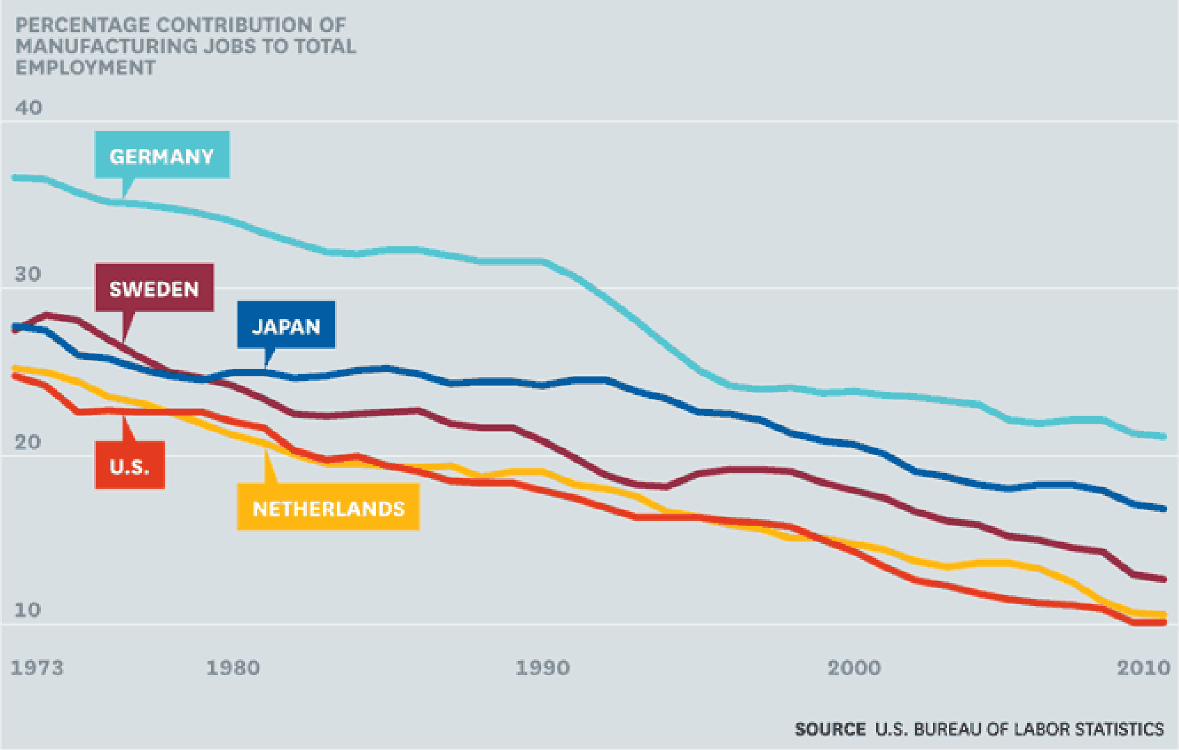
1. **Reach confidence and quality required for space use**
2. **Change the way we think / work today**

Manufacturing Technology in Europe

- Due to a number of reasons manufacturing within Europe has been in decline since the 1990's

  - ➢ Outsourcing of manufacturing
  - ➢ The need for cost reduction
  - ➢ Technology is decentralised to overseas suppliers

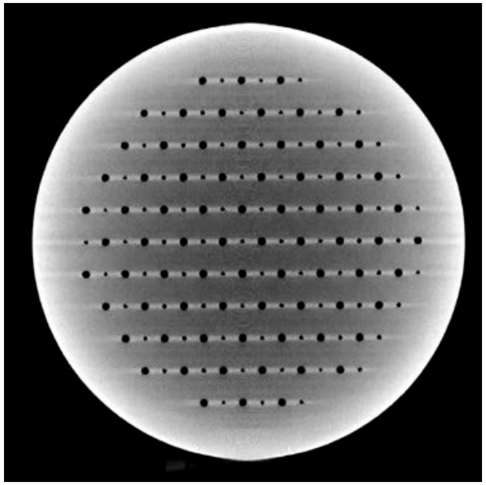
- This has resulted in certain competencies being permanently lost from Europe in general, not only Space



Additive Manufacturing (AM) at ESA

- **Challenges for Space Materials and Processes:**

1. **Low Mass**
2. **Small Production Series**
3. Very High Reliability
4. **Limited Manufacturing Processes**
5. **Small Geometries**
6. Very High Performances
7. **Challenging Material Procurement**



- **Why ALM?:**

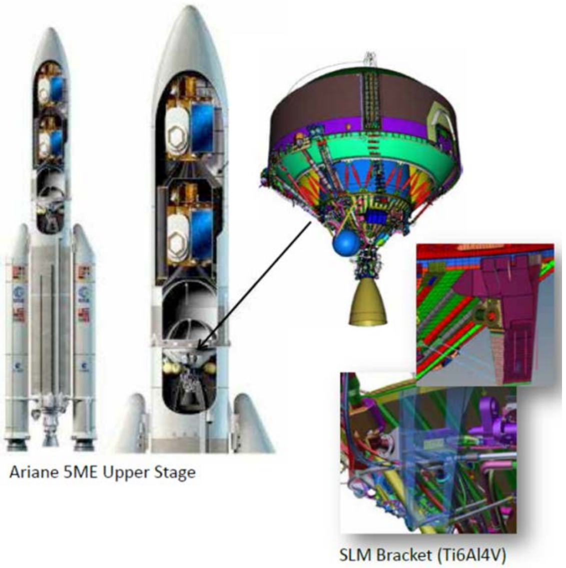
  1. Additive Layer Manufacturing is well fitted to Space hardware => very small series.
  2. Applied to many materials => metals, polymers, composites, ceramics for space but also food (for astronauts), living cells and organs (for telemedicine).
  3. Dimensions range from few micrometers to meters.
  4. Gains in performances with 2 digits => mass saving 40 to 90%, lead time reduced by weeks, suppress complex assemblies and controls.
  5. Environmentally friendly => excess material is re-used instead of being down-graded through re-cycling.
  6. Could be used for in-orbit manufacturing .

  Several developments are currently running under ESA funding including RF hardware, antennas components, propulsion, thermal management and structures

AM for Launchers

ISCAR bracket Airbus

- Upper stage Ti-6Al-4V bracket
- Market opportunities: **Ariane 5ME**/ Ariane 6
- Result in **20-25 brackets** / launcher
- **> 30 %** mass savings
- Verification approach: topology optimisation in consideration of fracture control
- Ongoing FLPP project



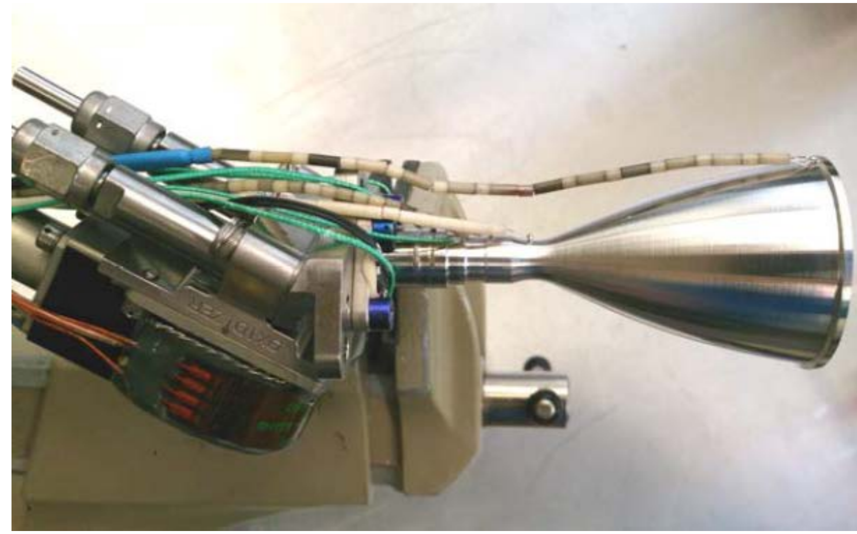
AIRBUS
DEFENCE & SPACE

A Major Achievement

World´s first 3D printed platinum combustion chamber for space applications !!!

Successfully Hot Firing Campaign 5th of May, 2015:

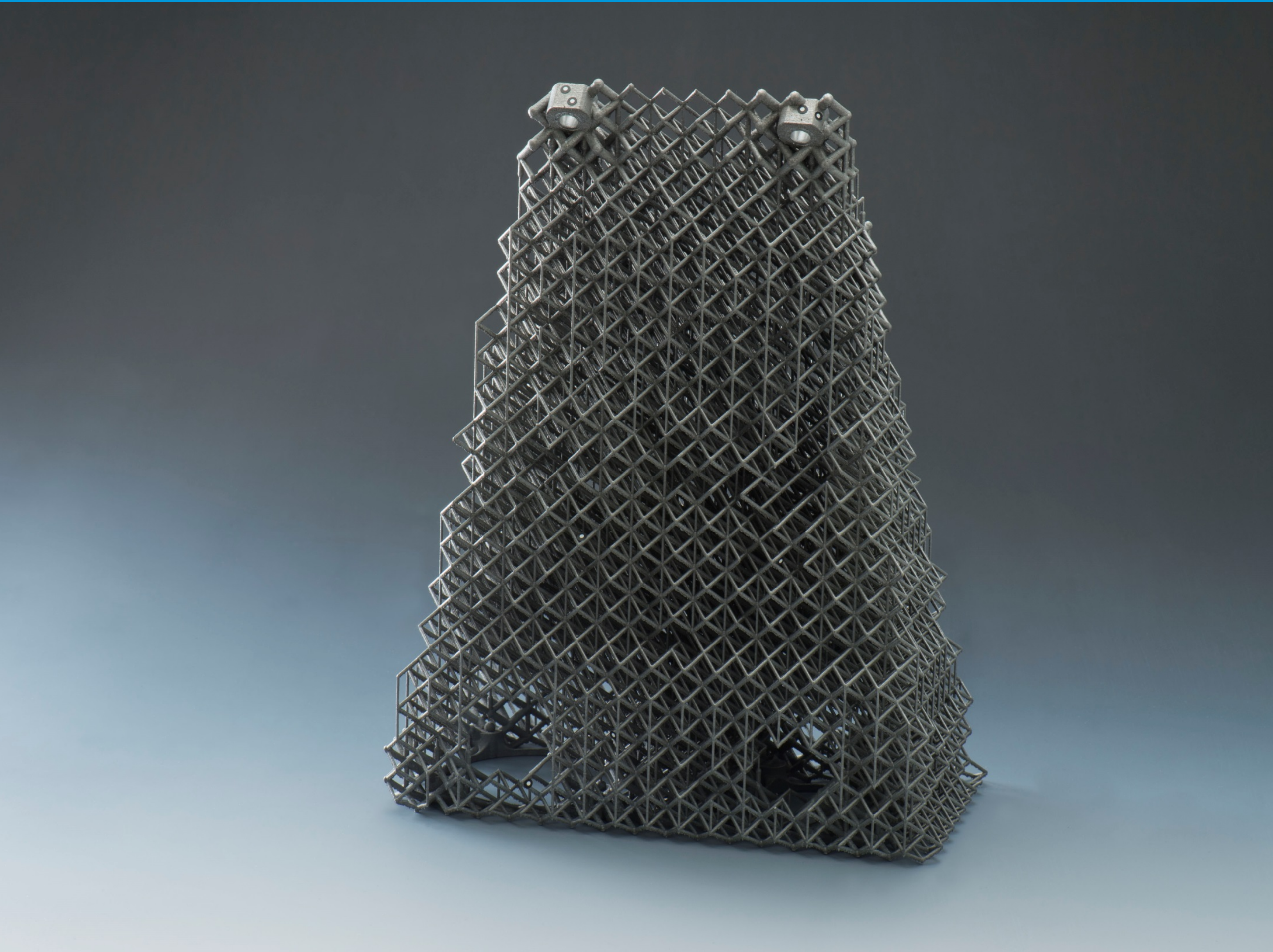
- **1,1 hrs firing time**
- **618 ignitions**
- **26 thermal cycles**
- **with a 32 min longest single burn**
- highest throat temperature of **1253°C** was reached



AIRBUS DEFENCE & SPACE

Fraunhofer IWU

Fraunhofer IWS



However…: Challenges to Achieve Space Applications Quality and Confidence Levels

1. **Design challenges:**
   - Current design tools do not allow taking full benefit from AM capabilities
     - Design tools do not include AM specific features
     - Design tools not compatible with AM machine programmes
     - Design rules for AM not fully established
2. **Manufacturing challenges:**
   - Raw material procurement not under full control => high impact on part manufactured
     - Change in powder characteristics
     - Unclear traceability of powders, unclear powder procurement
     - Develop new materials specifically for AM processing
   - Manufacturing process stability
     - Two machines from same manufacturer produce slightly different output
     - Process monitoring
     - Understanding of changes of process parameters impact on final product

However…: Challenges to Achieve Space Applications Quality and Confidence Levels

3. **(Space) Qualification / validation challenges:**
    - Change of paradigm: classical qualification methods (at Product level) do not apply to AM made parts
        - Material evaluation samples not always representative of the part
        - Materials allowables to be defined
        - Process verification methodologies (NDI) to be established and qualified
        - PA requirements to be established
    - **Capability approvals are necessary in the future!**

4. **Standardisation challenges:**
    - AM dedicated standards not fully established yet
    - AM dedicated ECSS to be issued

ALL of the ABOVE IS ADDRESSED IN ESA R&D/ECSS ACTIVITIES

Status of the AM ECSS Proposal

1. **AIM G of the Roadmap:** Develop the required normative framework for AM made hardware (ECSS)
2. **Motivation:**
   - An ECSS standard is required which shall establish the processing and quality assurance requirements for space parts produced by Additive Manufacturing
   - Profiting of existing international standards (e.g. ISO, ASTM) for AM
3. **Status:**
   - In agreement with the ECSS TA a WG is established with the following objectives:
     - Map the current state of the art w. r. t. AM standardization (already performed)
     - Establish gaps and needs w. r. t. \space standardization
     - Define the work plan for the AM ECSS
     - ToR of the WG in preparation ➔ **Kicked-off**

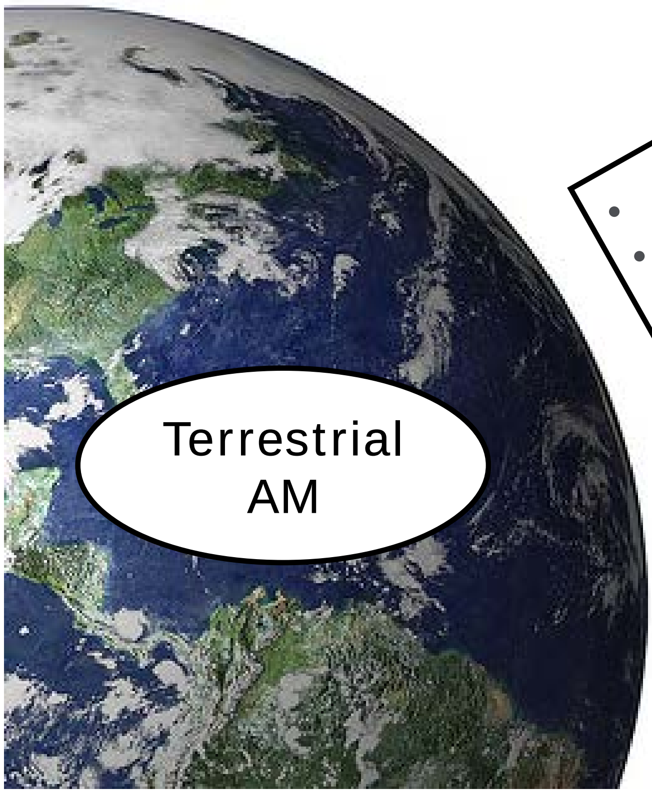
EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

ASTM F42

ISO/TC 261

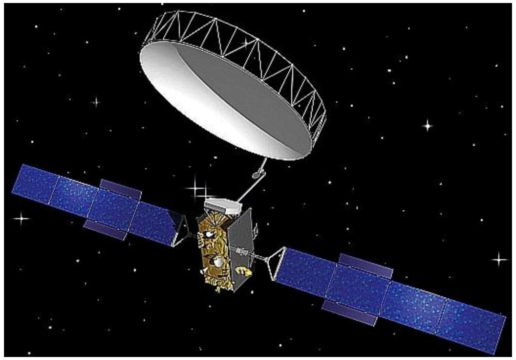
European Harmonisation Roadmap on Additive Manufacturing for Space

- Roadmap proposes about 30 types of parts (AIM A)
- Roadmap proposes technology developments (Aims B to F)
- **Roadmap endorsed by the IPC**



- Aim B: Design
- Aim C: Material supply
- Aim D: Processing
- Aim E: Post processing
- Aim F: Qualification
- Aim G: Standardisation

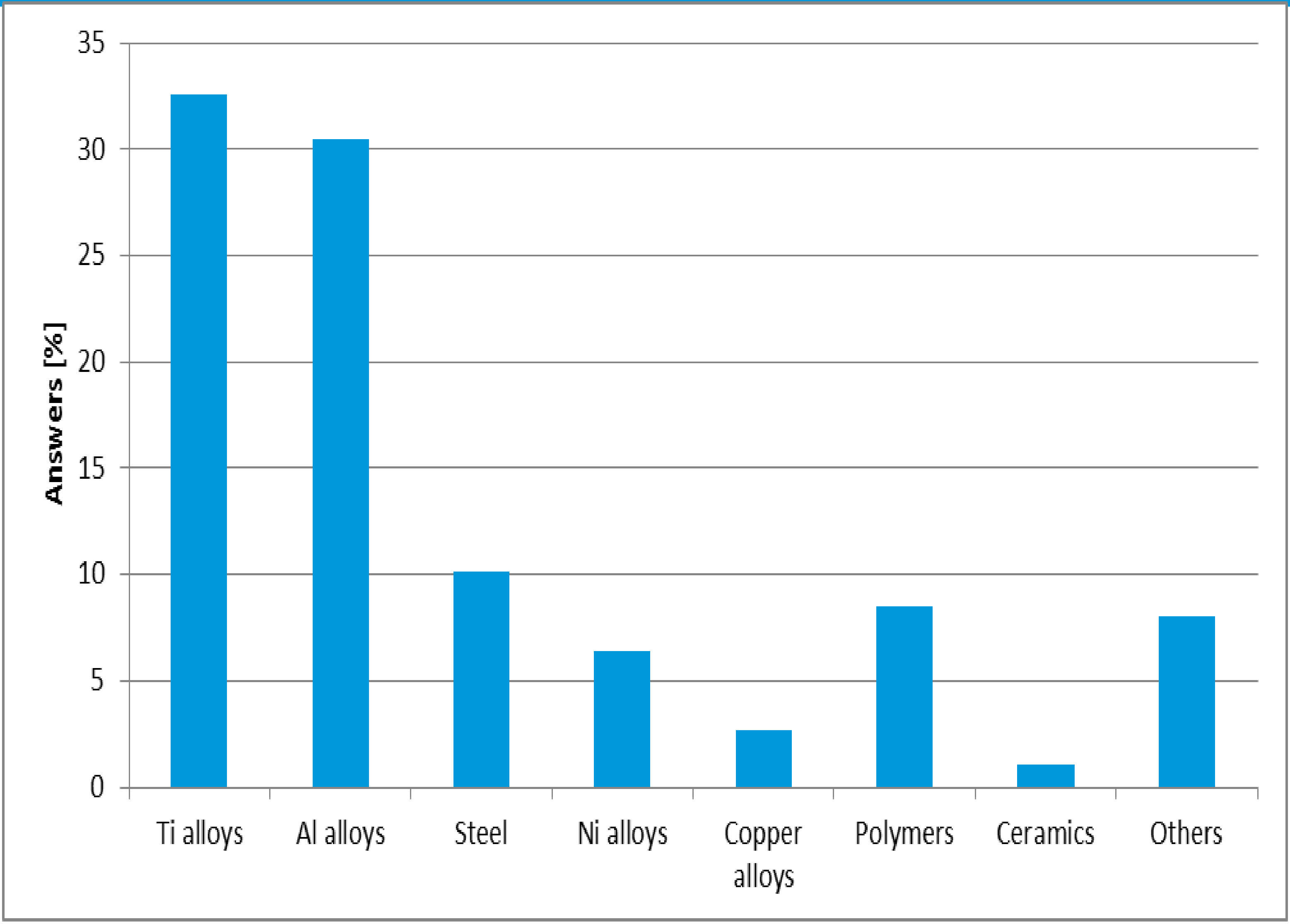
End-to-end AM process



Aim A

Image source: dragoart.com

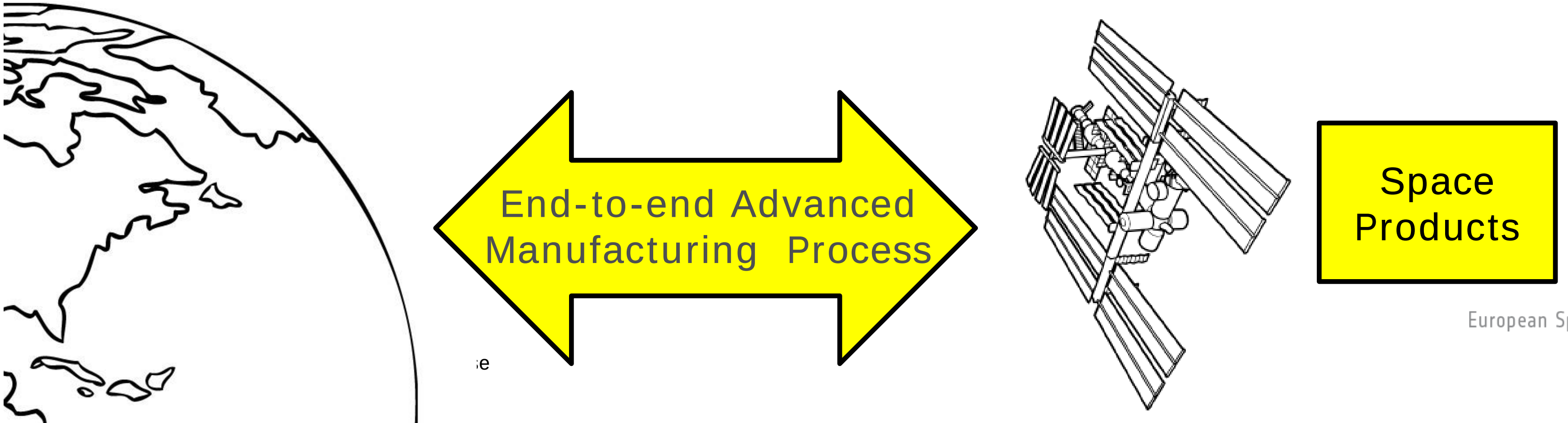
European Harmonisation Roadmap on Additive Manufacturing for Space



Agency

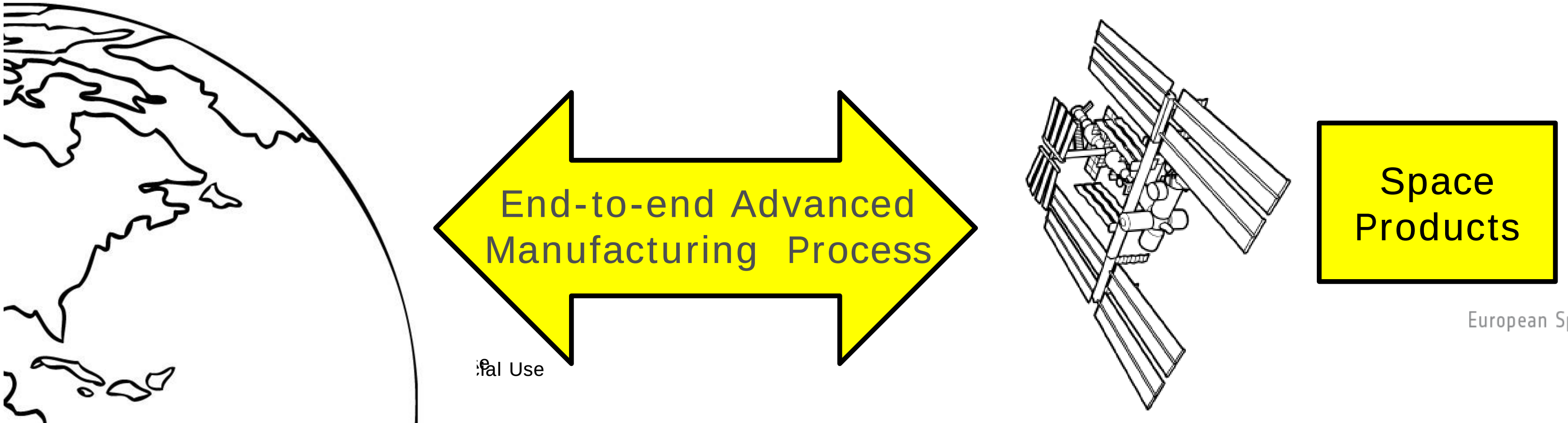
Advanced Manufacturing
ESA Cross Cutting Initiative

- Advanced Manufacturing (AM) cross cutting initiative has the following objectives:
  - ➢ Identify and implement new manufacturing technologies for space applications enabling:
    - ✓ Design freedom
    - ✓ Performance improvement
    - ✓ Costs reduction
    - ✓ Lead time reduction (from concept to manufacturing)
  - ➢ To create new high performance Space products by actively reducing the limitations imposed by the traditional manufacturing processes/concepts



Advanced Manufacturing ESA Cross Cutting Initiative (2)

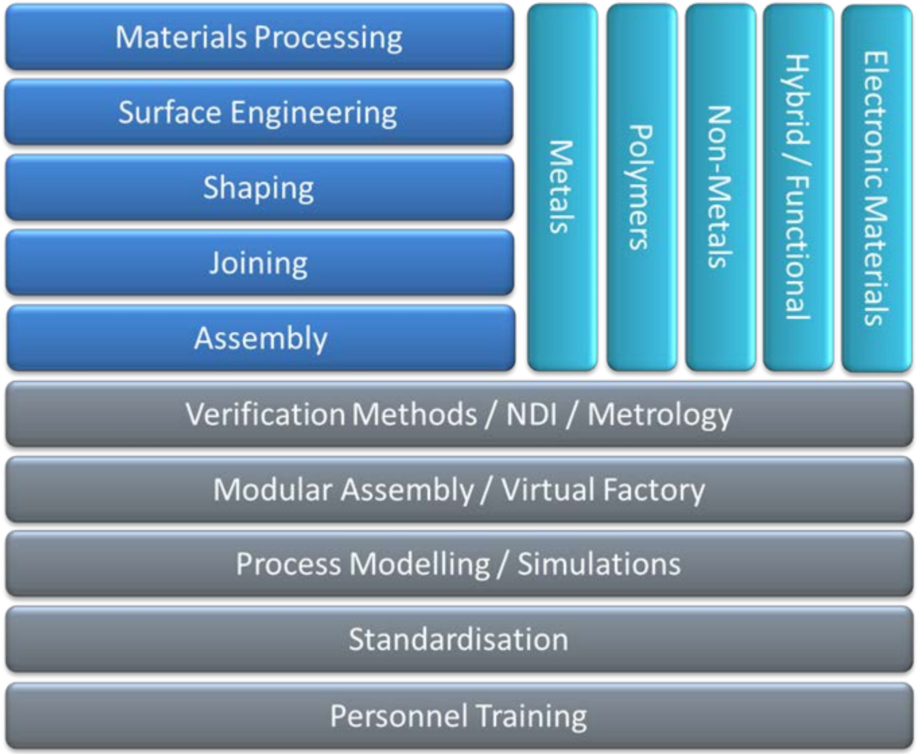
- Foster multi-sectorial cross-fertilization, facilitating spin-in / spin-out opportunities across different high-end technology and industrial domains and infrastructure
- Take advantage of other Programs supported by the EU (AMAZE, DEPLOYTEC, ThermoMag, etc.)
- Promote creation and dissemination of design and verification / qualification / standardization methodologies maturing creating the market and its uptake
- Maximize European Space industry competitiveness



Programme Structure

The first step is to identify

- the manufacturing processes (Dark Blue)
- the material types/ categories (Light Blue)
- Cross cutting disciplines which apply (Grey)



Select and prioritise the required advanced manufacturing technologies

Group similar activities and TRL levels

- Basic Research and prep activities (TRL 0-3)
  - Funded via GSP and TRP
- Main technology levels (TRL 3-7)
  - Funded via GSTP, Programme specific technology programmes, end user missions
- Qualification, verification and standards (TRL 4-8)

GSTP-6 Element 1 Potential Activities Advanced Manufacturing

GSTP-6 Reference	Title	Budget(K€)
	Materials Processing	
G61A-001QT	Low Cost Manufacturing of Engineering Ceramic Materials for Space Applications	400
G61A-002MS	3D Weaving processes for realisation of near net shaped hardware	500
G61A-003QT	Extended pot life resins for out of autoclave processing for large and complex part	600
G61A-004QT	Novel Low temperature curing resins for enhanced out of autoclave processing for large and complex space composites structure	1,200
G61A-005MS	Integrated Optical Fibres in Launcher and Spacecraft Composite Structures	500
G61A-006QT	Powder Metallurgy Based Materials for High Wear Resistance, High Hardness and High Temperature	600
G61A-007MS	Manufacturing of Interfaces for Thermo-Plastic Structures	400
	Surface Engineering	
G61A-008QT	Low cost/low temperature functional ceramic coating	500
	Shaping	
G61A-009MS	3D Honeycomb for curved structure manufacturing	600
G61A-010MS	Lattice Structures for Launchers and Spacecraft Produced with Automatic CFRP Processes	900
G61A-011QT	Advanced Forming Technologies for Complex Shapes	1,500
G61A-018QT	Additive Manufacturing Powder Material Supply Chain: Verification and Validation	1,000
G61A-019QT	Advanced aluminium alloys tailored for Additive Manufacturing space applications, targeting high end structural spacecraft parts	900
G61A-020QT	Development of large 3D printed structures: tank shells joined by FSW for ultimate cost reduction	2,500
G61A-021QT	Primary Structures made by Additive Manufacturing	1,200
G61A-022QT	Enhanced contamination control for Additive Manufacturing	500
G61A-023QT	Development of a manufacturing process for large polymer structures for spacecraft applications: high strength electrical and/or thermally conductive polymers for Additive Manufacturing	700
G61A-024QT	Integrated recycling and manufacturing process for on planet manufacturing using polymers materials	700
G61A-025MS	Development of Design Methods for AM including CAD Design / FEM analysis / Manufacturing features	900
G61A-026MP	Additive Manufacture of In-space Engine chambers	2,000
G61A-027MS	Development of embedded thermal functions in structural parts using 3D printing	900
G61A-028QT	Development of a gradient sized mesh for cryocooler by Additive Manufacturing	1,000
G61A- 029ET	Development of one single part integrating waveguide filter, bends, couplers, supporting structures made by Additive Manufacturing -	1,000
G61A-031MM	Development of thermally ultra-high stable compact grating spectrometer mirrors via Additive Manufacturing	500
G61A-032MM	Development of low areal density Aluminium alloy mirrors using Additive Manufacturing	400
G61A-033MS	Development of a Compliant Mechanism Based on Additive Manufacturing	500
G61A-034MS	Development of shock absorbing protection made of crushable materials (lattice / cellular structure) using Additive Manufacturing	600
G61A-035ET	Evaluation and consolidation of Additive Manufacturing processes and materials for the manufacturing of RF hardware	1,000
	Joining	
G61A-012QT	Dissimilar transition joints for Aluminium demisable structures	400
G61A-013QT	Surface Nano-Texturing of Metals for Adhesive Bonding Improvement in Metal/CFRP and Metal/Metal Structural Joining.	600
	Assembly	
G61A-014MS	Integral Manufacturing of Full CFRP Sandwich Structures for Optical Benches	700
G61A-015MS	Manufacturing of Large Friction Stir Welded Structures for Satellites and Launchers Applications	1,200
G61A-016QT	Rigid-flex PCB interconnections	900
G61A-017QT	High Density PCB assemblies	1,800
	Total	**29,600**

More information:
www.emits.esa.int => news

Summary and Next steps – Additive Manufacturing

- Additive Manufacturing is considered a potential **game changer** and **enabling technology for future space missions**
- **However,** AM should **not** be seen as **a "global" solution**
- **However**, challenges exist:
  1. Design Challenges
  2. Manufacturing Challenges
  3. Qualification/Validation/Standardization Challenges
- ESA has proposed a strategic roadmap in order to address and solve the presented challenges with a **harmonized approach**, **avoiding distracting European resources and efforts** and avoiding the **"mushrooming effect"**
- The proposed Roadmap collates the most important activities required to allow End-Users develop **high performances parts while saving on mass, cost and lead-time**
- All proposed activities will aim at **establishing Additive Manufacturing capabilities** through manufacturing of breadboards / demonstrators **endorsed by the End-Users**
- **AM ECSS WG kicked-off in Q1 2016**
- **Additive Manufacturing** is one of the building blocks of a larger program launched by ESA ➔ **Advanced Manufacturing for Space Applications**


QUESTIONS?