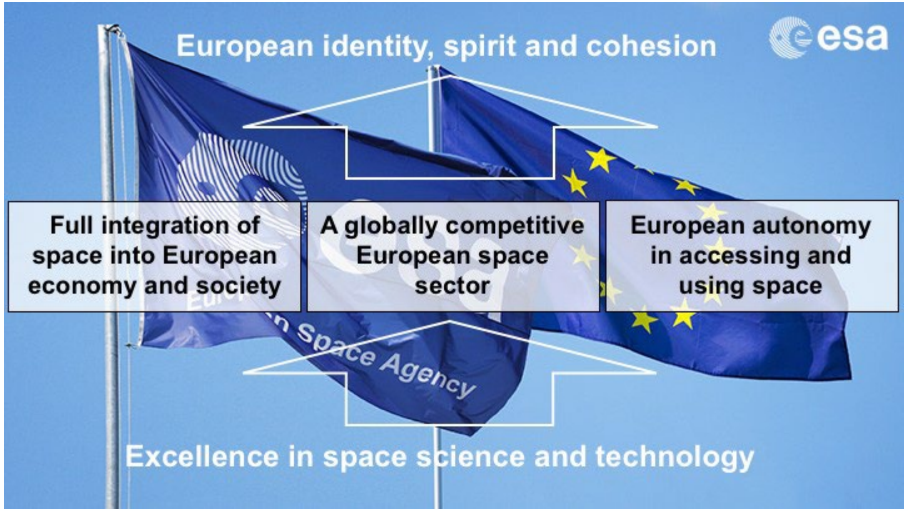
ESA Strategy for Additive Manufacturing Technology

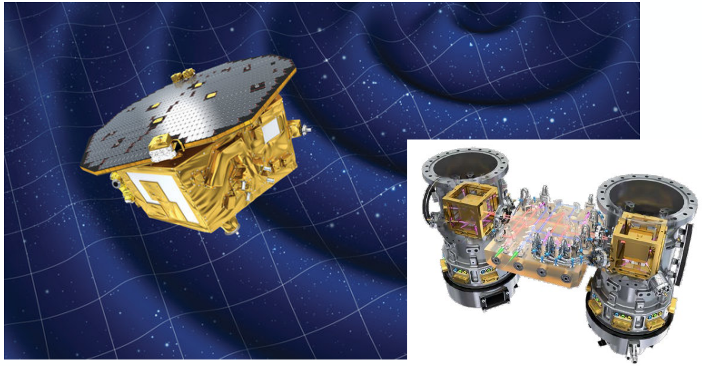
Thomas Rohr
Head of Materials and Processes Section
Mechanical Department
European Space Agency

Thomas.Rohr@esa.int

EASA-FAA Industry-Regulator AM Event, 8-12 November 2021

General Technology Strategy

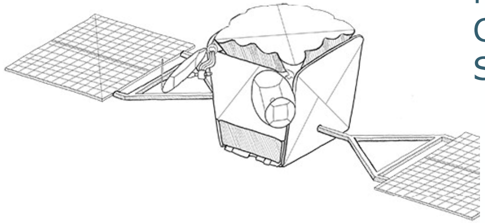




Unique science missions
Pushing frontiers

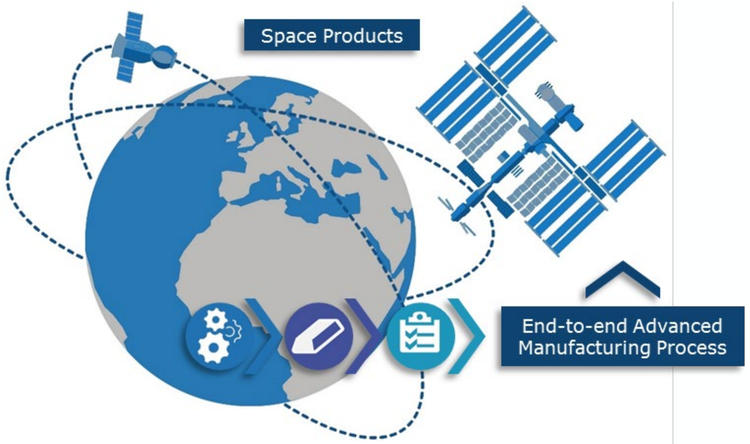
Technologies for full spectrum of activities

Mass market
Cost-driven
Simplification



Advanced Manufacturing - Objectives

- To create new high performance Space products by actively reducing the limitations imposed by the traditional manufacturing processes/concepts
- Profit of the ideal opportunities in Europe to spin-in the digital manufacturing technologies and Industry 4.0 to space
- Identify and implement new manufacturing technologies for space applications enabling:
  - Design freedom
  - Performance improvement
  - Costs reduction
  - Lead time reduction (from concept to manufacturing)



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

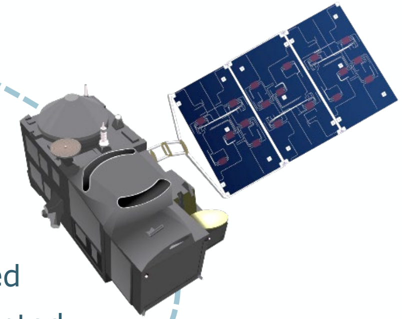
Aim G: Standardization

End-to-end AM process

Aim A:

Originally in 2015:

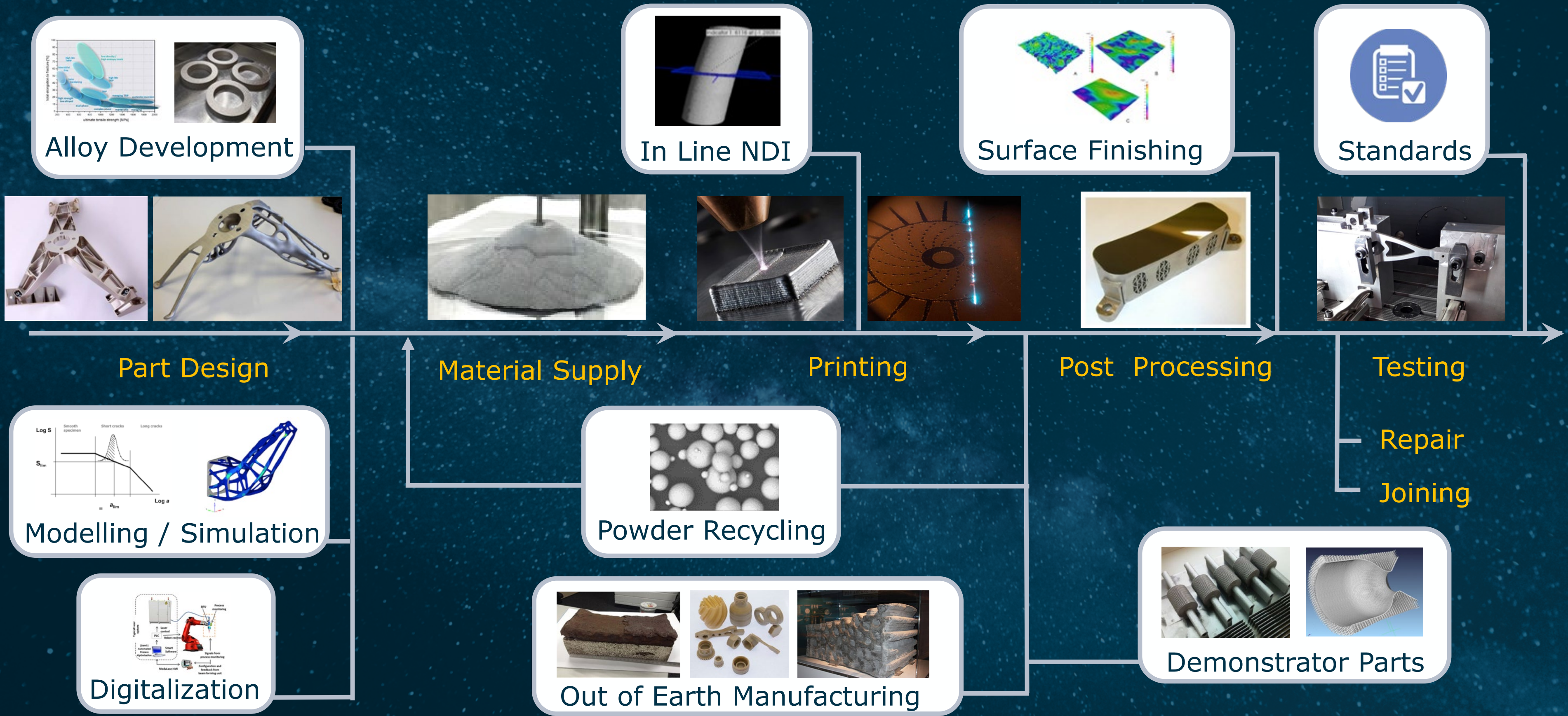
- More than **700 experts**
- **26 countries** represented
- **390 companies** represented
- **62 new members** joined the roadmap space community



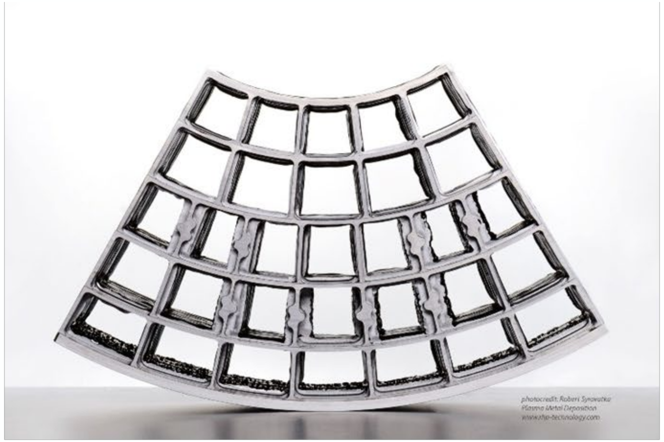
2nd Roadmap revision ongoing

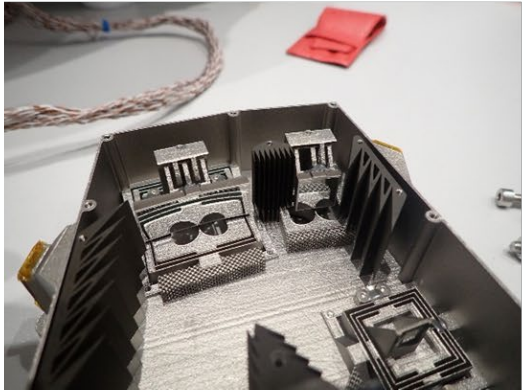
Image source: dragoart.com

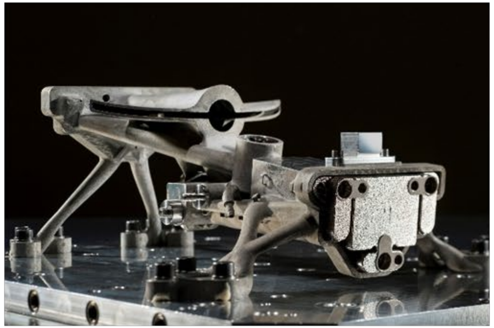
Additive Manufacturing – Areas of Interest



Additive Manufacturing Hardware

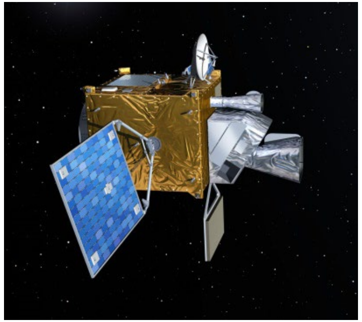




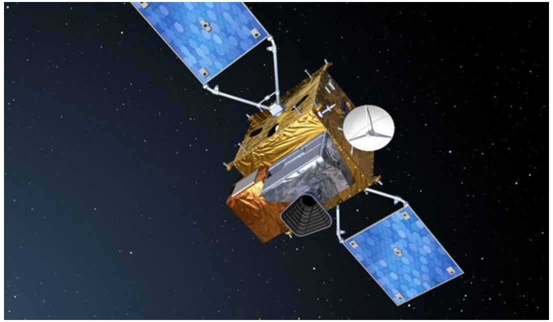


Examples of Recent AM Flight Hardware Developments

MTG



Sentinel 4



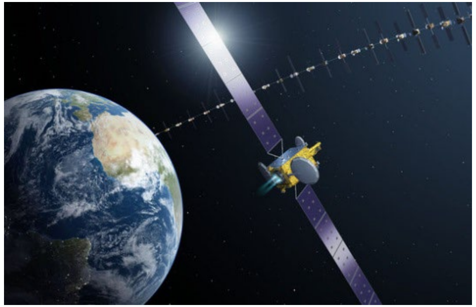
VEGA C

Ariane 6

Quantum

Juice

Electra



Standardisation

ECSS: European Cooperation for Space Standardisation - htps://ecss.nl

→ collaboration of Industry and national/international Agencies

Processing and quality assurance requirements for metallic powder bed fusion technologies for space applications
(ECSS-Q-ST-70-80)

→ EBM and SLM technologies for metals

→ Planned to be extended for further technologies

European Space Agency
Agence spatiale européenne


ECSS-Q-ST-70-80C
30 July 2021

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space product assurance

Processing and quality assurance requirements for metallic powder bed fusion technologies for space applications

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Together ahead. RUAG

ThalesAlenia Space
a Thales / Leonardo company

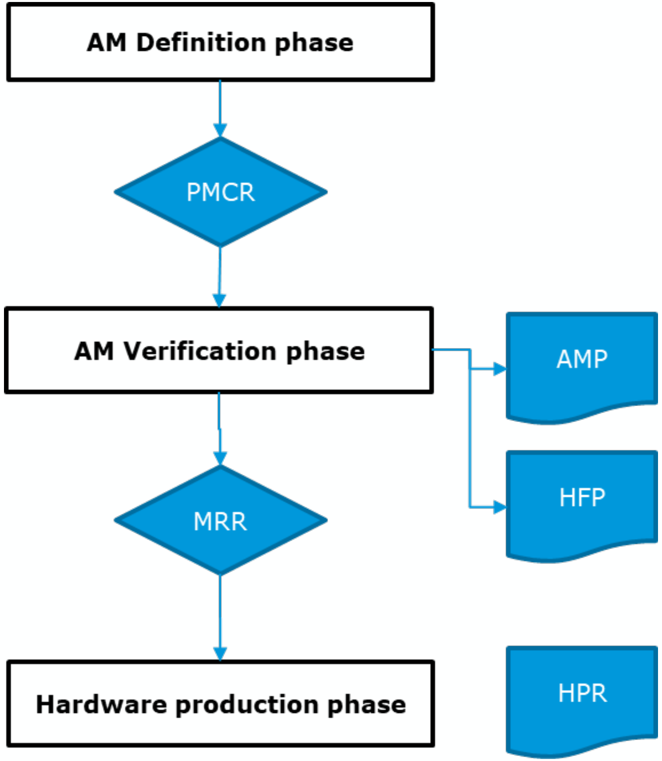
DEFENCE & SPACE

DLR

CENTRE NATIONAL D'ÉTUDES SPATIALES

We. Create. Space.

Standard Work Logic



Definition phase: Hardware requirement vs end to end manufacturing constraints

- PMCR: Preliminary Manufacturing Concept Review (requirements, safety class, AM end to end process).
- pAMP: Preliminary Additive manufacturing procedure (density, tensile tests)

Verification phase: material/process capabilities evaluation (sample level) and design verification (prototype level)

- AMP: Additive Manufacturing Procedure (end to end process parameters documentation to ensure AM part repeatability. E.g. powder batch, machine identification, processing parameters). Mechanical tests to define allowable (A or B values), NDI capabilities assessment. **(CDR)**
- HFP: Hardware Fabrication Procedure (definition of the conditions how the hardware has to be produced. E.g. build job configuration, witness samples)
- MRR: Manufacturing Readiness Review

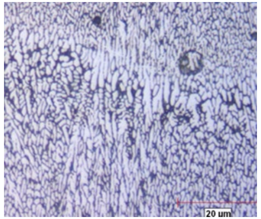
Hardware production phase: production and testing of flight hardware.

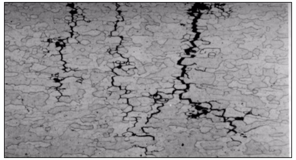
- HPR: Hardware production report

AM Definition Phase

Functional hardware requirements

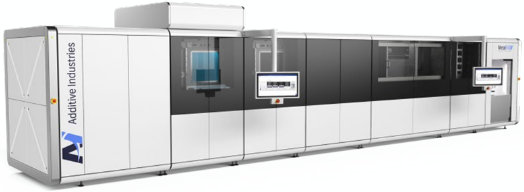
- Required mechanical properties
- Leak, burst pressure
- Dimensions & Geometrical tolerances
- Cleanliness and surface roughness
- Environmental requirement





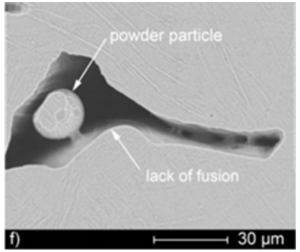
AM design constraints

- Build envelope
- Inspectability of the design with NDI
- Design rules
- Machine-material properties link
- Post processing



Criticality of the AM process

- Material properties, acceptance criteria for defects
- Achievability of cleanliness requirements
- Safety class

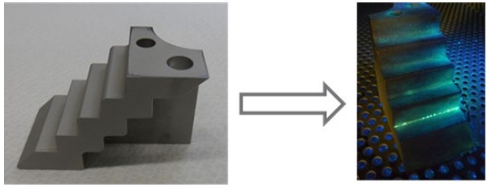


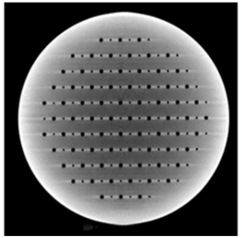
Post processing techniques

- Suitability for selected material, design, etc.
- Machining constraints

NDI techniques

- Detection limits
- Acceptance criteria





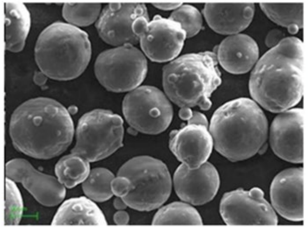
AM Verification Phase

AM Manufacturing procedure (AMP) →

- Feedstock
- AM process parameters
- Post Processing windows at sample level
- NDI technique verification

Successful verification on **specimen level** leads to Additive Manufacturing Procedure **(AMP)**

AMP applies for one material and one machine, reuse for different designs using same processing parameters



Hardware fabrication procedure (HFP) →

- Build job configuration
- Supporting structure strategy
- In process samples definition
- (post) Processing windows at hardware level
- NDI technique verification at hardware level

Successful verification on **part (prototype)** level leads to Hardware Fabrication Procedure **(HFP)**

Hardware production phase

- Production of component(s) and specimens
- Non-destructive Testing
- Testing of witness specimens
- Proof testing results at part level

Source: VTT Finland, Magna Parva, the MTC

Source: RUAG Switzerland

Pro-FACE Assessment Tool for Additive Manufacturing

Need

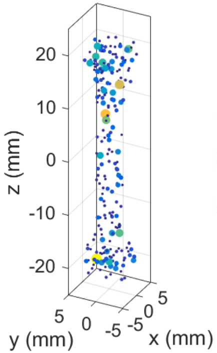
- Perform structural/fracture control assessment of AM flight hardware
- Material/Component qualification/verification
- Reduce conservatism and optimize technology performances
- Uncertainties quantification

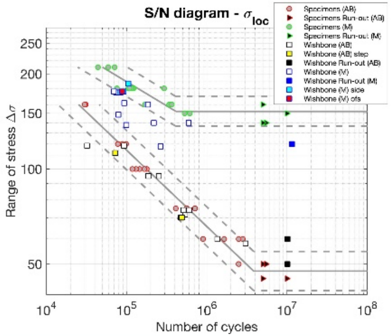
Methodology

- Starting point: component CT-Scan, mechanical test data
- Probabilistic approach covering defects occurrence/distribution (statistics of extremes)
- FEM interface with defects population/analysis
- Fatigue life prediction and scatter/Probability of failure

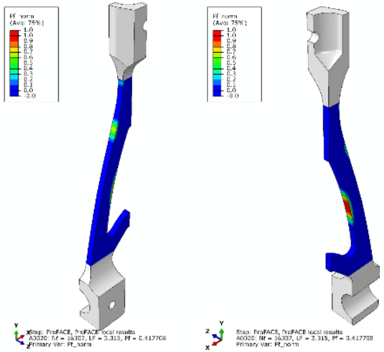
Tool

- Pro-FACE (developed and patented by the Politecnico of Milan)
- Tool interfacing with ABAQUS/NASTRAN
- Benchmarking performed (AM Benchmarking Centre) on AlSi10
- Benchmarking with Airbus Aircraft performed on Ti-6Al-4V
- Materials Database filling (AlSi10, Ti-6Al-4V, INCONEL 718)
- Future Testing Methodologies for costs minimisation/CT Scanning minimisation





Map of predicted failure probability



Location of actual failures

Smart Manufacturing → 2nd compendium

Data Acquisition
- Embedded sensors
- Test data
- Process monitoring

Tool Development
- Metallurgical Models
- Through Process Models
- Neural Networks

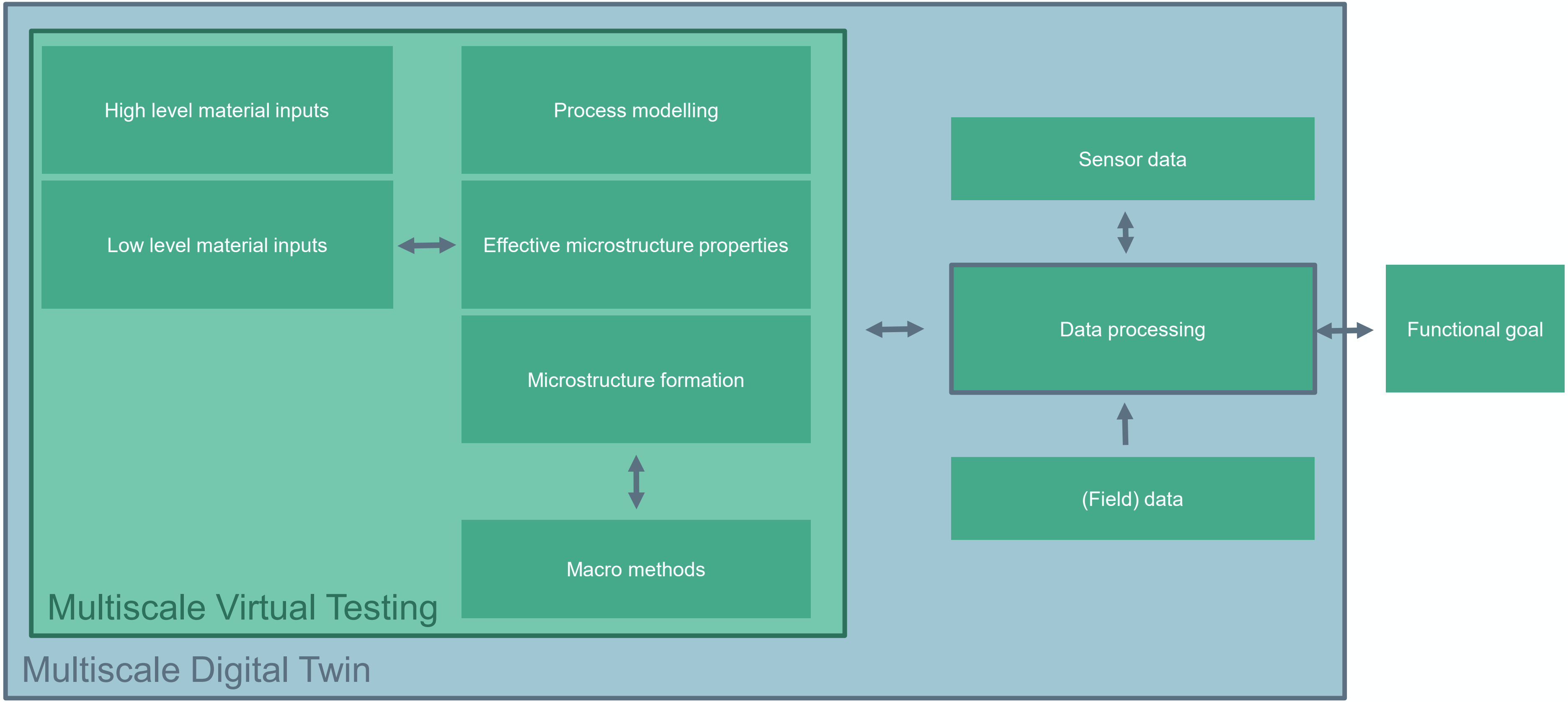
Qualification
- Tailored Approach
- Flying prototypes
- COTS / Open Source

Data Manipulation
- Intelligent process control
- Machine Learning / AI
- Virtual Twins

Standardisation
- ESA to drive standardization
- Process Monitoring/Control
- Cyber Security

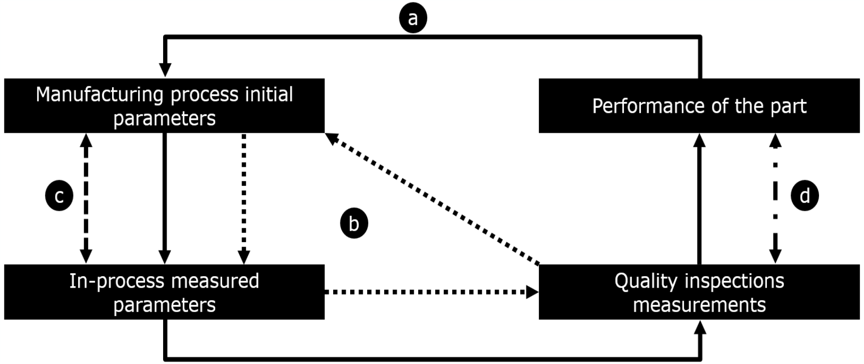
Virtual Testing
- Reduce the number of tests
- Explore more cases
- Change the traditional design space

Virtual Testing and Digital Twins – modularity



Certain modules can be omitted based on the actual needs

Functional goals of Digital Twins



a. End-to-end Digital Twins,
b. Shop floor Digital Twins,
c. In-process Digital Twins,
d. Behaviour Digital Twins

(e.g. for predictive maintenance and Remaining Useful Life),

Approach is manufacturing process agnostic:

- additive manufacturing (e.g. Selective Laser Melting, Electron Beam Melting, Direct Metal Deposition, Wire Arc Additive Manufacturing,);
- welding (Laser Welding, Electron Beam Welding),
- solid state joining (Friction Stir Welding, Linear Friction Welding),
- CFRP manufacturing (Filament Winding, Injection Molding, Resin Transfer Molding, Vacuum Assisted Resin Infusion, etc.);

Approach is materials agnostic:

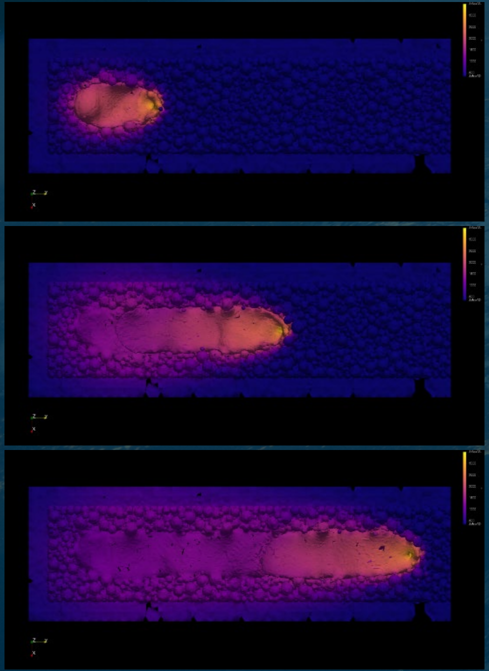
- Metals, ceramics, CFRP, soft matter, etc.

Approach is Parts properties agnostic:

- Base properties: physical, thermal-physical, static and dynamic mechanical,
- Parts geometric and functional constrains (also internal quality constrains, e.g. cracks, pores, inclusions, etc.).

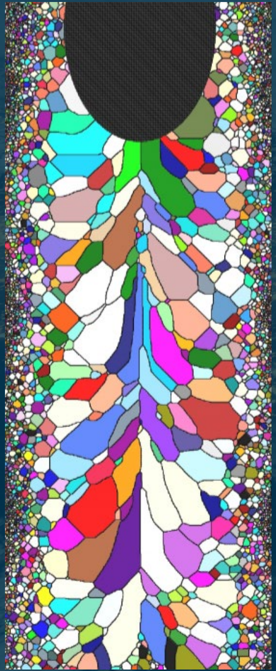
ICME for SLM (example)

Physics based modelling of the process



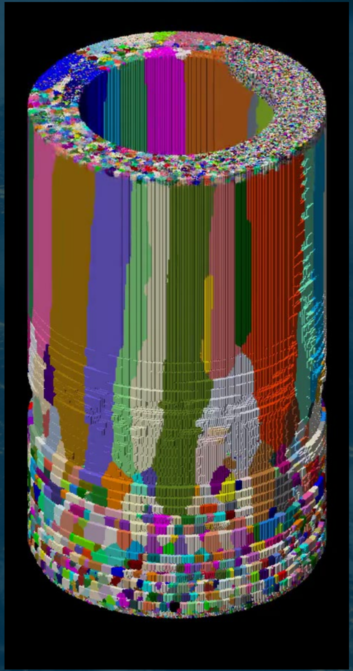
Source: ESA

Microstructure modelling



T. M. Rodgers, J. A. Mitchell, and V. Tikare, Modelling and Simulation in Materials Science and Engineering, 25, 064006 (2017)

Effective properties of the part

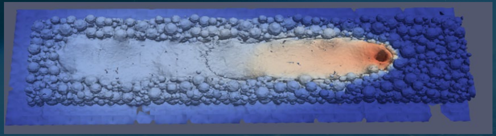
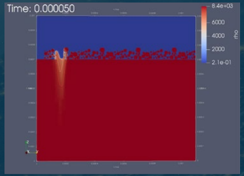


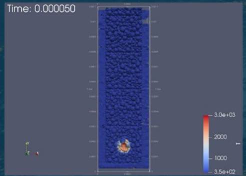
T. M. Rodgers, J. D. Madison, V. Tikare, Computational Materials Science 135, 78-89 (2017)

V&V for ICME for SLM (example)

Physics based modelling of the process ⟷ Microstructure modelling ⟷ Effective properties of the part

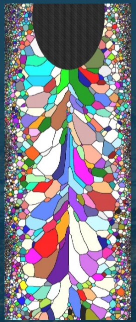
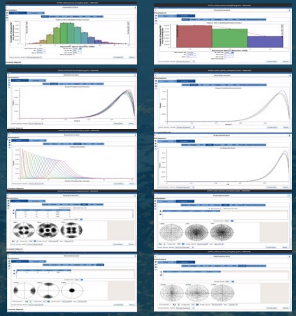
simulation



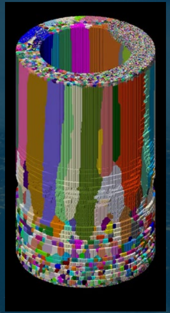
Multi-phase multi-physics process description

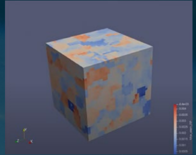
Source: ESA

Numerical and statistical description of microstructures (sRVE)

T. M. Rodgers, J. A. Mitchell, and V. Tikare, Modelling and Simulation in Materials Science and Engineering, 25, 064006 (2017)



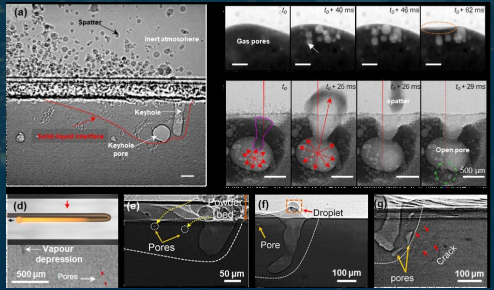



Grains with increased affinity to crack

Micro-scale elasto-plasticity and fatigue mechanics – CP / EVD FIP

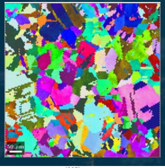
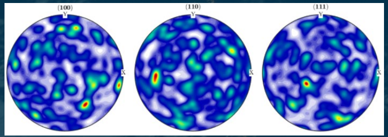
T. M. Rodgers, J. D. Madison, V. Tikare, Computational Materials Science 135, 78-89 (2017)

V&V



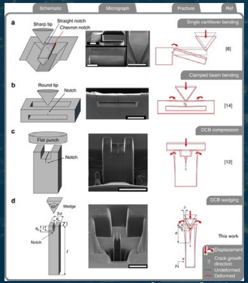
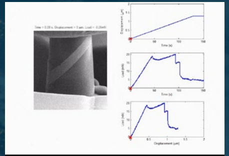
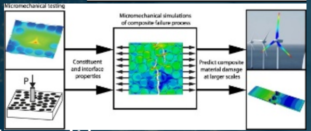
Numerical software experimental validation with S-XCT

Leung C. L. A., Marussi S., Atwood R. C., Towrie M., Withers P. J. & Lee P. D. In situ X-ray imaging of defect and molten pool dynamics in laser additive manufacturing. Nat. Commun. 9, 1355 (2018). DOI: 10.1038/s41467-018-03734-7

Experimental validation with EBSD and S-XCT

https://mtex-toolbox.github.io/

Experimental validation with micromechanical testing

M. Hardiman et al./Composite Structures 180 (2017) 782–798

Sernicola, G., Giovannini, T., Patel, P. et al. In situ stable crack growth at the micron scale. Nat Commun 8, 108 (2017).

https://alemnis.com/micropillar-compression/

AM22 Conference

Aims and Scope

The aim of the International Conference on Manufacturing for Aerospace and Space Applications is to promote and facilitate discussion and exchange of experience and information among members of the various mechanical engineering disciplines concerned with aircraft and spacecraft development, assembly, integration and verification.

Conference Themes

- Additive Manufacturing
- Joining Technologies
- Composite Manufacturing
- Digital Manufacturing
- Surface Engineering
- Electronic Materials and Processes
- Out of Earth Manufacturing
- Smart Materials
- Emerging Materials & Processes

Special Event - **Immature Technology Day** will take place on the 9th of March

https://atpi.eventsair.com/icam22/

Thank you for your attention!

Thomas.Rohr@esa.int
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