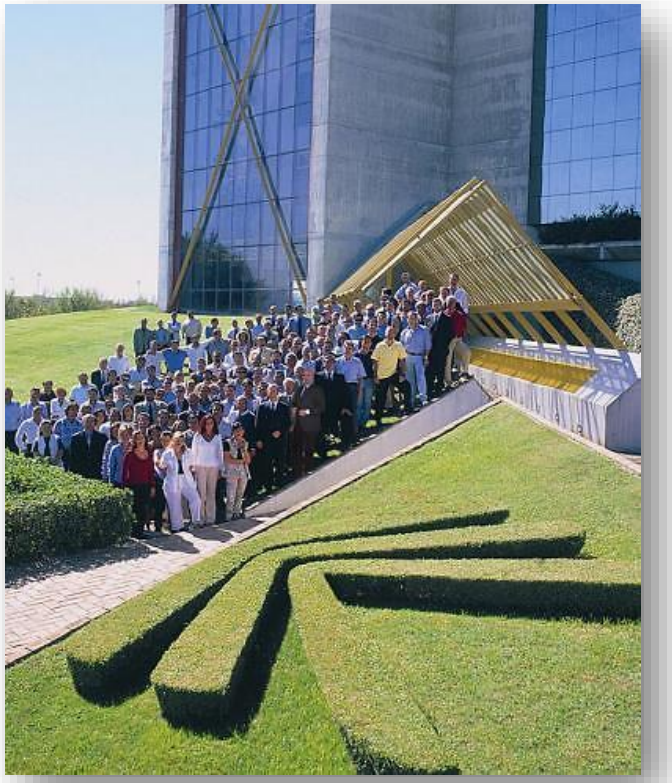
Metallic Additive Manufacturing through Electron Beam Powder Bed Fusion (EB-PBF): challenges and opportunities in the aeronautical and space sector

CIRA

Italian Aerospace Research Centre



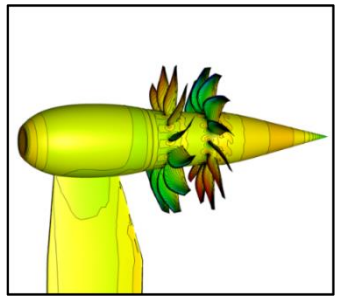
CIRA IN BRIEF

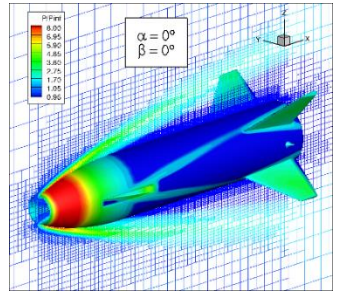
CIRA is a non-profit public-private partnership among:

- CNR (National Council for Research) 52%
- Campania Region 16%
- Italian Aerospace Industries 32%

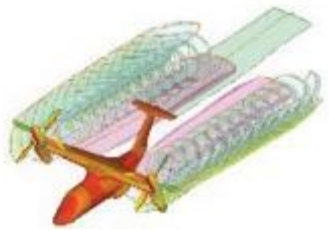
In 1989, the Italian **Government entrusted CIRA of** the **Italian Aerospace Research Program (PRORA) management** under the control of Ministry of Education, University and Research (MIUR).

- enhancement of scientific competences and expertise
- development and operation of strategic testing facilities
- development of strategic research programs





STRATEGIC AREAS

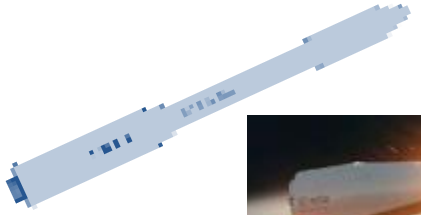


AVIATION

GREEN, SAFE, SECURE

&

DEFENCE



ACCESS TO SPACE
SPACE VEHICLES
EXPLORATION

&

DEFENCE

EARTH
OBSERVATION

FOR EARTH

&

DEFENCE

RESEARCH
INFRASTRUCTURES

&

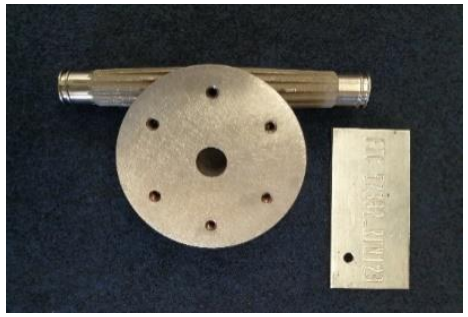
DEFENCE

Often described as the "third industrial revolution" **Additive Manufacturing** is changing the industrial landscape worldwide, particularly in high-end technology sectors, including **aerospace applications**.

Body Flap Support

Connecting Rod

NLG Fitting

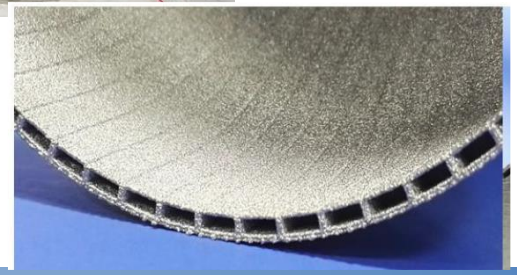


Flanges for fuel storage system

Injection head
of space engine

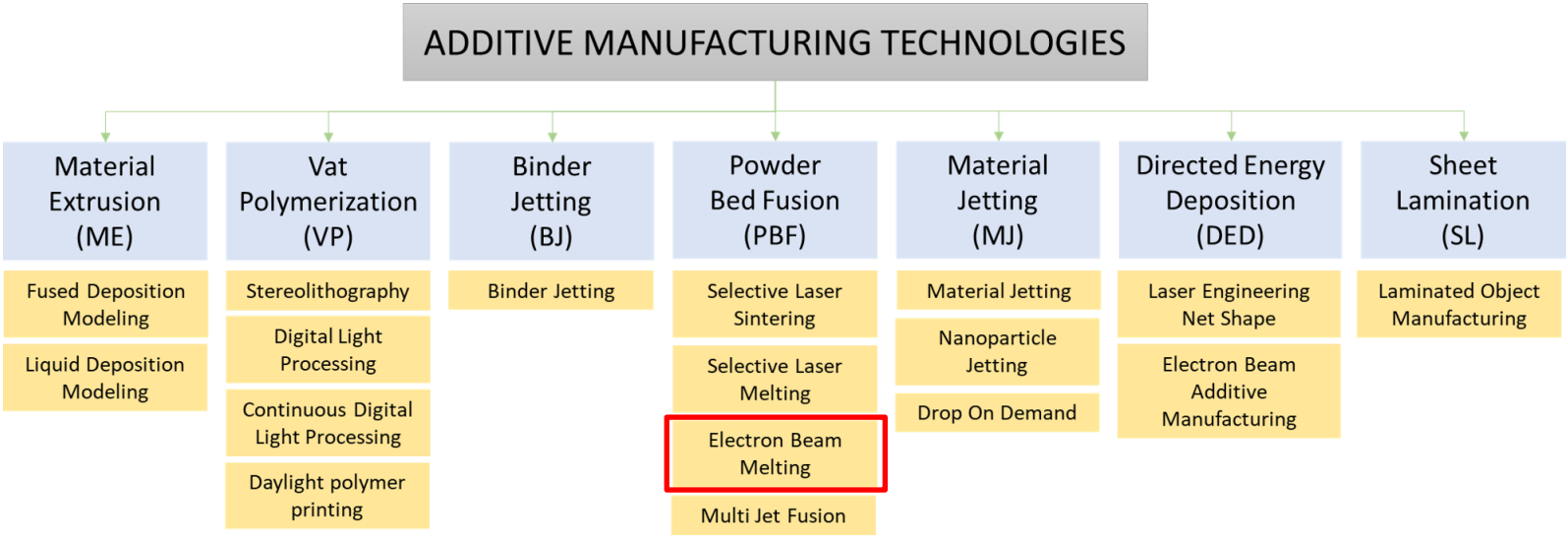
Combustion Chamber mock up

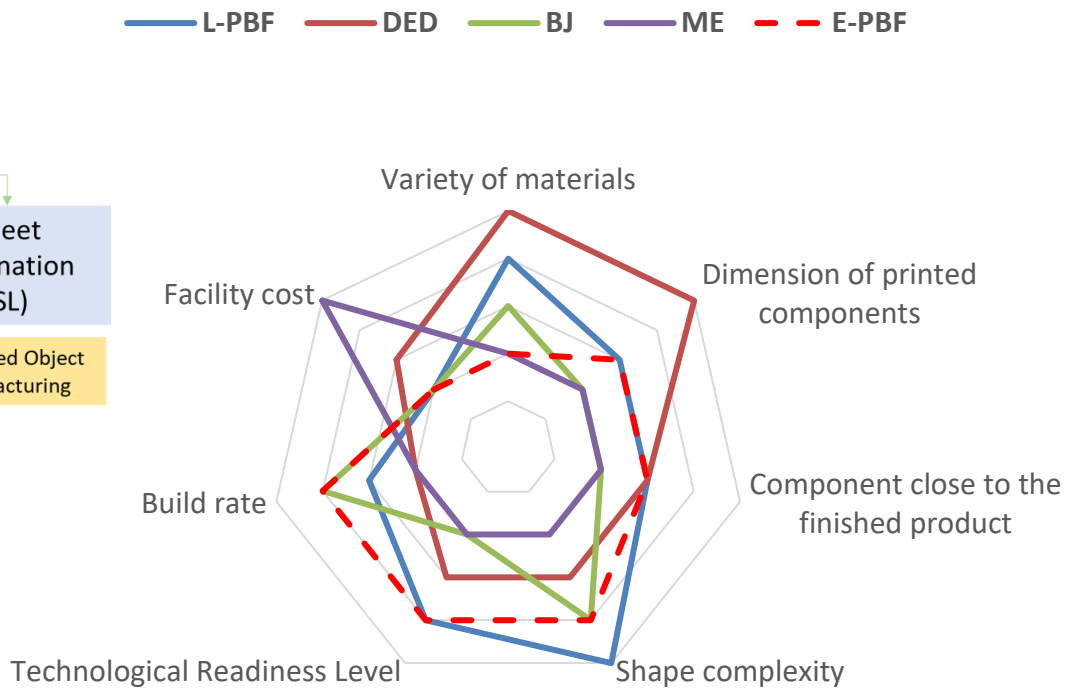
Back cover of space capsule



ADDITIVE MANUFACTURING DEFINITION ACCORDING TO ASTM F2792

"The process of joining materials to make objects from 3D-model data, layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining"





Strategic Objectives

The strategic objective of the "*Additive Manufacturing Lab*" is to ***design, characterize and optimize*** innovative processes for the manufacturing of structural metallic components for aeronautical and space applications with the final target to reduce the manufacturing costs, time and scraps and obtaining more performant structures.

The laboratory is focused on study and research activities related to **Additive Layer Manufacturing** of **Titanium alloy** and in particular to the **Electron Beam Powder Bed Fusion (EB-PBF)** technology.

ARCAM A2X

POWDER RECOVERY SYSTEM (PRS10) for Ti6Al4V

POWDER RECOVERY SYSTEM (PRS11)

For a 2nd material to be defined

AS-300A Hall Flowmeter

Flowability ASTM B213

Apparent Density ASTM B212

GE Additive

Certificate of Analysis

Customer: GE Additive Italy Srl
Material description: Arcam Ti6Al4V powder
Size: 45-106 µm
Specification: UAC065-170510 & ASTM F2924
Part number: 400844
Purchase order No.: 50750
Batch No.: P1452
Quantity: 40 kg

Powder chemical composition (wt. %)

Element	ASTM F2924	UAC065-170510	Measured	Testing method	Status
Carbon (C)	< 0.08	< 0.08	0.01	ASTM E1941	Conforming
Oxygen (O)	< 0.20	0.11-0.20	0.12	ASTM E1409	Conforming
Nitrogen (N)	< 0.05	< 0.05	0.01	ASTM E1409	Conforming
Hydrogen (H)	< 0.015	< 0.0	0.002	ASTM E1447	Conforming
Iron (Fe)	< 0.30	< 0.30	0.09	ASTM E2371	Conforming
Aluminum (Al)	5.50 - 6.75	6.00 - 6.75	6.36	ASTM E2371	Conforming
Vanadium (V)	3.50 - 4.50	3.50 - 4.00	3.92	ASTM E2371	Conforming
Yttrium (Y)	< 0.005	< 0.005	0.001	ASTM E2371	Conforming
Others, each	< 0.10	< 0.10	< 0.10	ASTM E2371	Conforming
Others, total	< 0.40	< 0.40	< 0.40	ASTM E2371	Conforming
Titanium (Ti)	Balance	Balance	Balance		

Chemical analysis laboratory: Luvak Inc. (722 Main Street, P.O. Box 597, Laydon MA, USA, 01505)

Powder characterization

Particle size distribution per ASTM B214

Particle Size	% By Mass	% By Mass	Description	Required	Measured	Status
< 25 µm*	< 0.7	0.2*	Conforming			
25-45 µm	Report	4.1	NA			
45-106 µm	> 90.0	91.0	Conforming			
106-150 µm	Report	4.6	NA			
> 150 µm	< 0.2	0.0	Conforming			
< 45 µm	< 5.0	4.3	Conforming			
> 106 µm	< 5.0	4.6	Conforming			

Particle size distribution per ASTM B822 (Coulter® LS 13320)

Description	Required	Measured	Status
D10	Report	51 µm	NA
D50	Report	89 µm	NA
D90	Report	104 µm	NA

*Standard ASTM B214 applies to powder sizes 45 microns and higher. The results are for information only.

Description	Required	Measured	Status
Flow rate per ASTM B213			
Flow rate (sec/50 g)	Max. 29	24	Conforming
Apparent density per ASTM B212			
Apparent density (g/cm³)	Min. 2.40	2.6	Conforming
Tap density per ASTM B527			
Tap density (g/cm³)	Min. 2.7	2.8	Conforming

Powder characterization by: AP&C Inc. (3765 La Vérendrye, suite 110, Boisbriand, Québec, Canada, J7H 1R8)

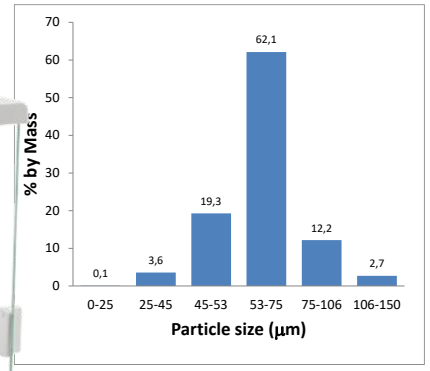
☒ Inspection certificate done according to EN 10204 type 3.1. We hereby approve the analysis and certify that the above values conform to the requirements of the purchase order above

2019-01-08 Date — Alexander England Quality department

This powder was specially designed for use on the Arcam EBM systems. Powder characterization requirements are based on Arcam EBM internal procedure. Arcam EBM submits this certification as the confidential property of the client. It shall not be reproduced except in full, without the written approval of Quality department of Arcam EBM. The recording of false, fictitious, or fraudulent statements or entries on this certificate may be punished as a felony under federal law.

PARTICLE SIZE ANALYZER

ASTM B214



micromeritics®
Effective Solutions for Material Characterization

HELIUM PYCNOMETER

Skeletal Density ASTM B923

ANALYTICAL BALANCE

PRECISION BALANCE

MICRO-HARDNESS TESTER DM2

ASTM E384

micromeritics®
Effective Solutions for Material Characterization

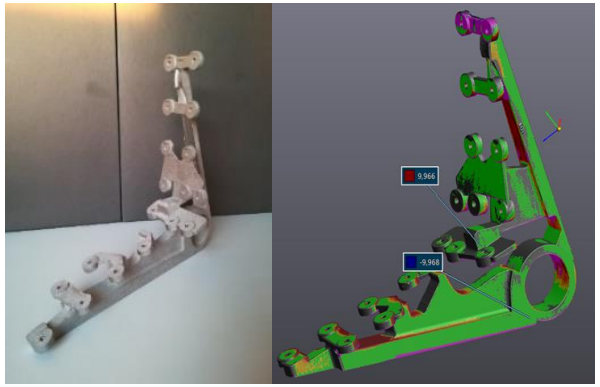
HELIUM PYCNOMETER

7 AXIS HEXAGON ABSOLUTE ARM WITH LASER SCANNER

STRUCTURED-LIGHT 3D SCANNER

N.2 3D Scanner

- Construct Digital 3D Model
- Check Dimensional Accuracy



OTHER CIRA CAPABILITIES

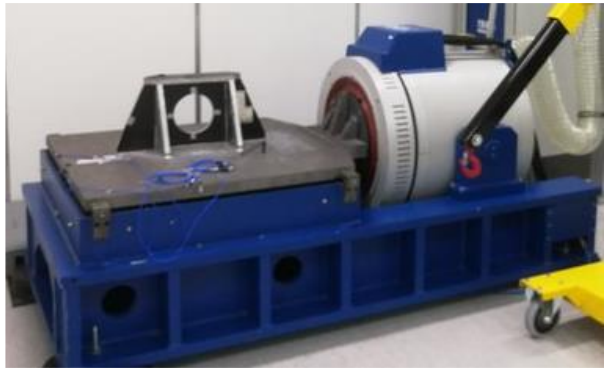
MECHANICAL TEST

MTS810
cell load capacity of 250kN

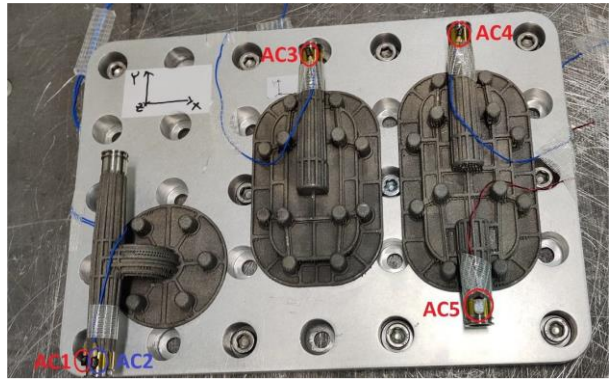
INSTRON4505
cell load capacity of 100kN

STATIC TESTS ON AM PARTS

VIBRATION TEST



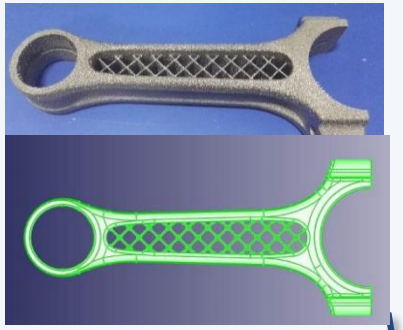
CIRA SHAKER TIRA TV 59335-440



VIBRATION TESTS ON AM PARTS

Samples
for process
characterization

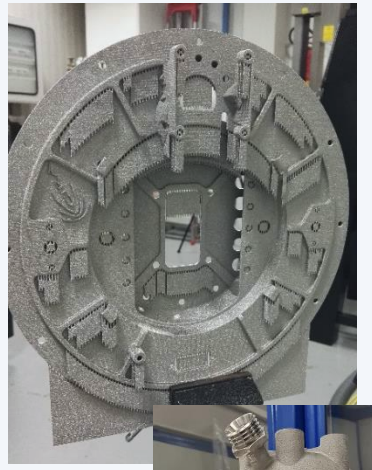
Connecting Rod



NLG Fitting

Shape complexity

Back cover of space capsule



Injection head
of space engine

Flanges for fuel storage system

Satellite antenna filter

Combustion Chamber mock up

CHARACTERIZATION

TECHNOLOGICAL FEASIBILITY OF COMPONENTS REALIZATION

Ti6Al4V EB-PBF Characterization

TENSILE TEST

Influence of:

- Surface finish
- Growing direction
- Layer thickness
- Shape
- Dimensions
- Temperature

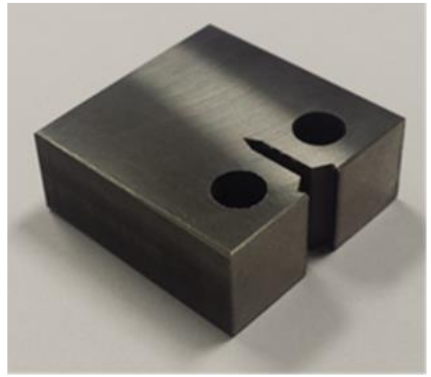
FATIGUE TEST

n.3 batches tested:

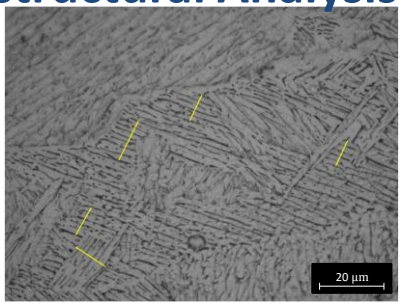
- MACHINED HIP
- MACHINED NO HIP
- AS BUILT NO HIP

CREEP TEST

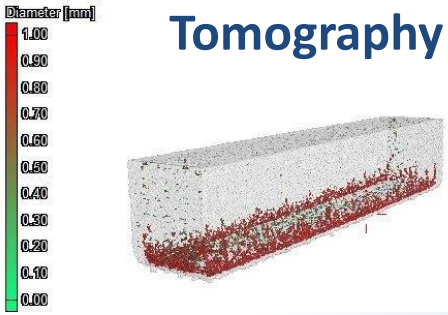
FRACTURE THOUGNESS K_{IC} CRACK GROWTH PROPAGATION



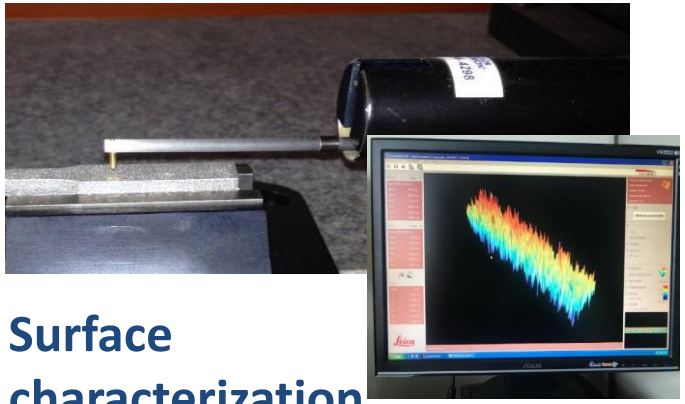
Microstructural Analysis



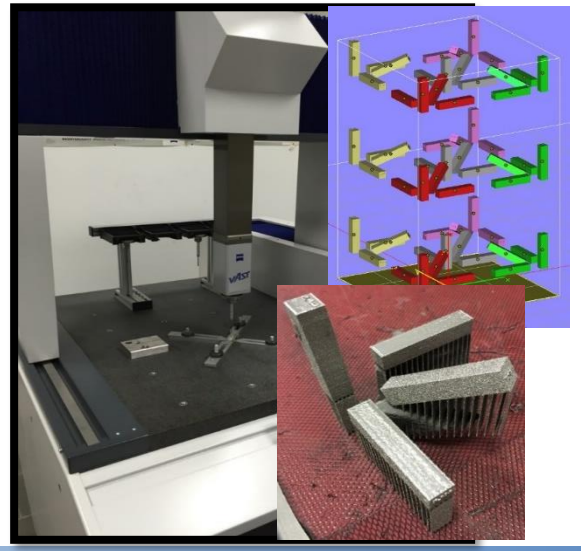
Tomography



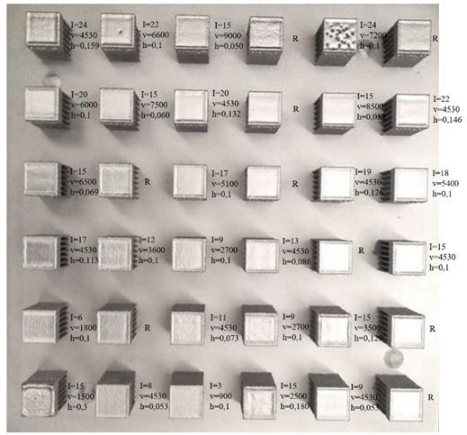
Surface characterization

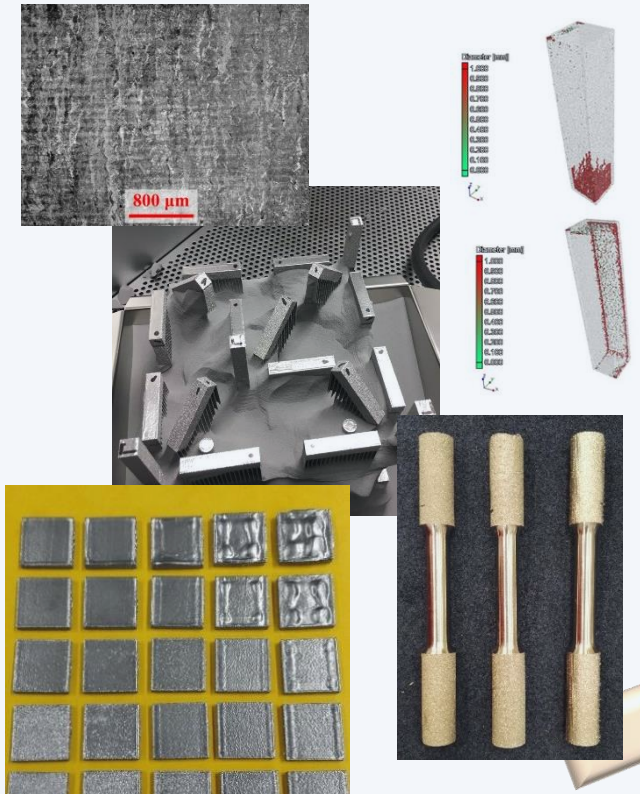


Dimensional characterization



Process Parameters Optimization

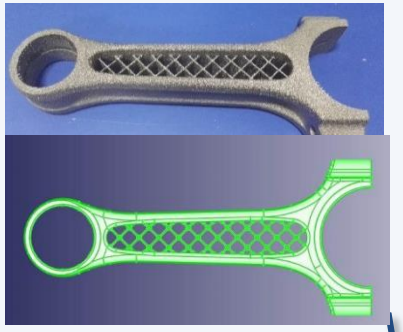




Samples
for process
characterization

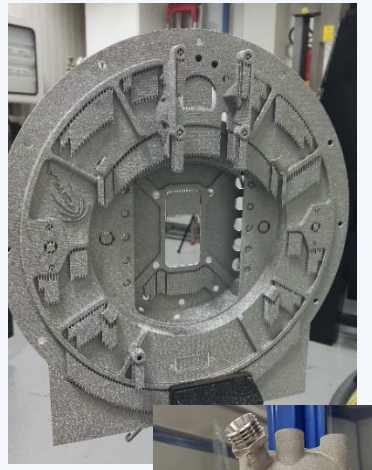
Shape complexity

Connecting Rod



NLG Fitting

Back cover of space capsule



Injection head
of space engine

Flanges for fuel storage system

Satellite antenna filter

Combustion Chamber mock up

CHARACTERIZATION

TECHNOLOGICAL FEASIBILITY OF COMPONENTS REALIZATION

TEAM (MATURAZIONE **TE**CNOLOGIE INNOVATIVE PER **A**L**M**) is a research project funded by the Italian Aerospace Research Program (**PRORA**) under the control of Ministry of Research.

OBJECTIVE: Development of knowledge regarding innovative technologies based on **ALM** by increasing skills in each of the crucial phases that characterize the manufacturing process.

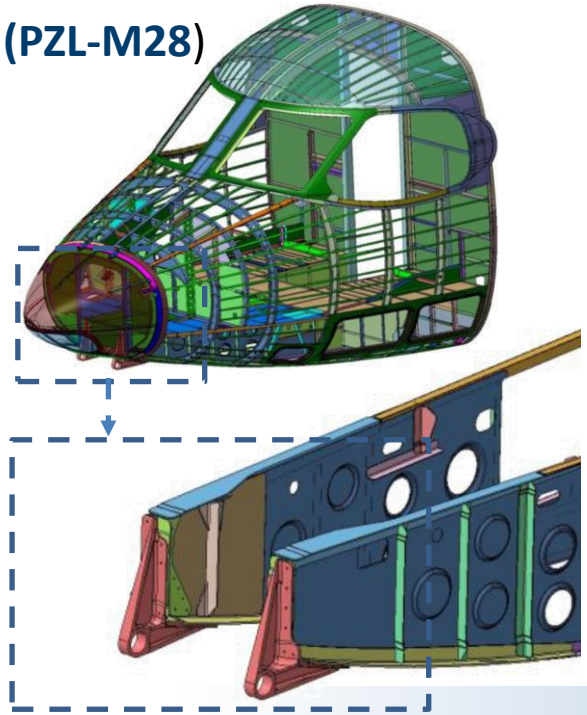
- Think additive **Design** ALM oriented and optimization methods
- **Materials** customized and designed ad hoc for ALM processes
- **AM process** complementary to the present EBM system
- **Post-processing** to improve mechanical, surface and dimensional properties
- Testing and **qualification**

SAT-AM (Smart Aircraft Affordable Manufacturing) is a H2020-CS2 Project

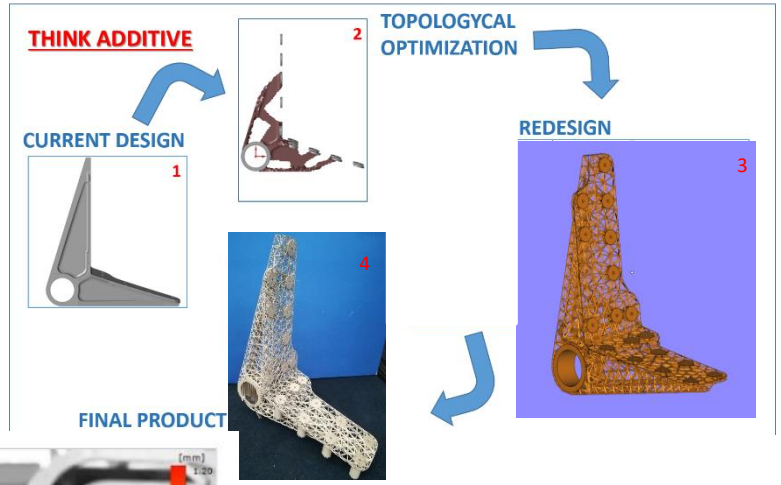
Objective: to develop technologies for manufacturing lighter and cheaper airframes

Applicant No	Participant Organisation Name (Short)	Country
1 (Coordinator)	Instytut Lotnictwa (ILOT)	Poland
2	Polskie Zakłady Lotnicze Sp. z o.o.(PZL Mielec)	Poland
3	EUROTECH Sp. z o. o. (Eurotech)	Poland
4	SZEL-TECH Szeliga Grzegorz (Szel-Tech)	Poland
5	P.W. "Metrol" Dariusz Dąbkowski (P.W. Metrol)	Poland
6	ULTRATECH Sp. z o.o. (Ultratech)	Poland
7	ZAKŁADY LOTNICZE Margański & Mysłowski S.A. (ZLMM)	Poland
8	Centro Italiano Ricerche Aerospaziali (CIRA)	Italy

(PZL-M28)

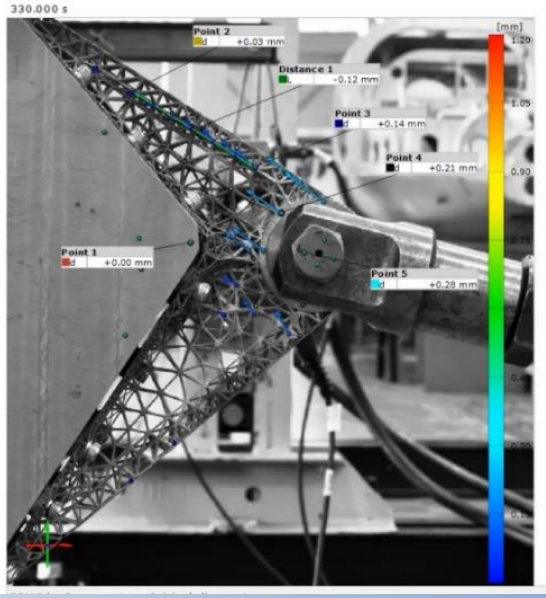


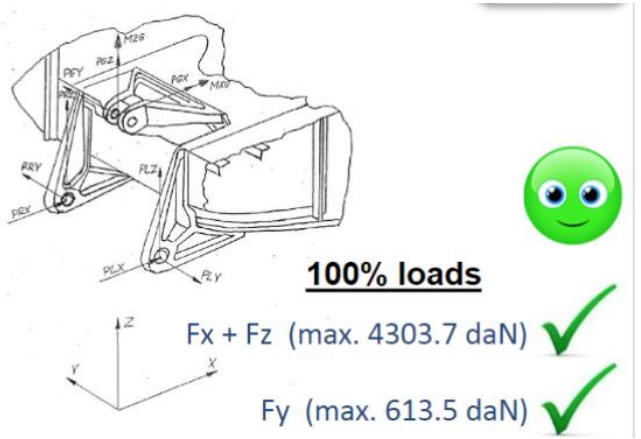
Design



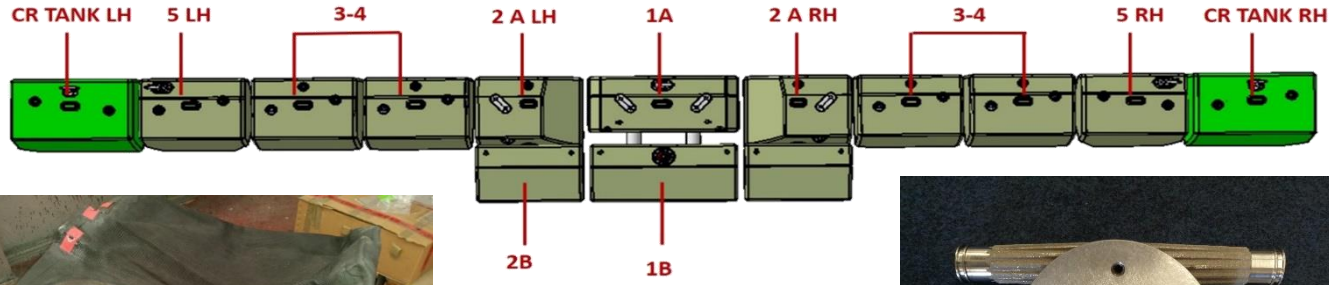
Re-design and manufacturing in Ti6Al4V with ALM tech (473g) of Fuselage NLG fitting currently in AA 2020-T6 (524g) ➔ -10%

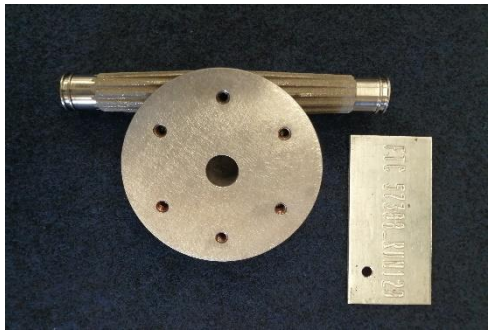
Testing

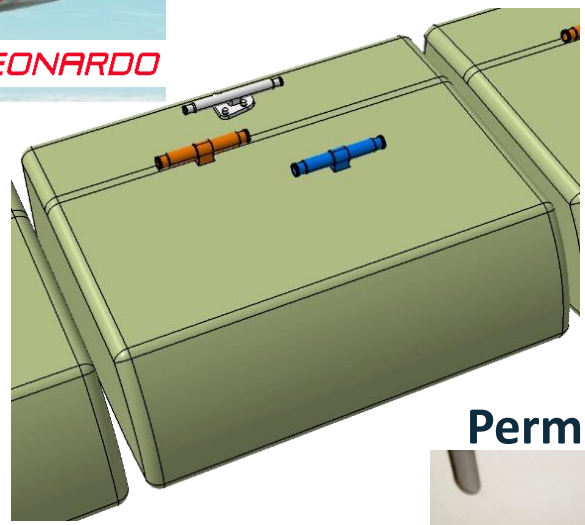




DEFENDER Development, manufacturing, testing and qualification of an innovative fuel storage system (of the innovative tiltrotor NGCTR) **is a H2020-CS2 Project.**





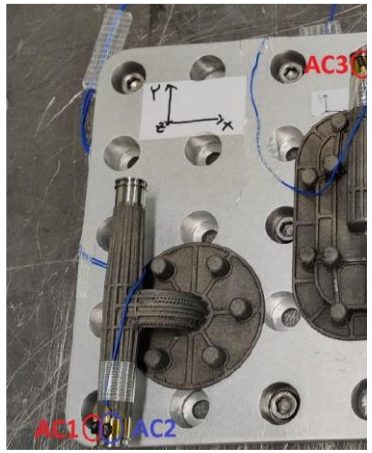


QUALIFICATION OF ALM FLANGES

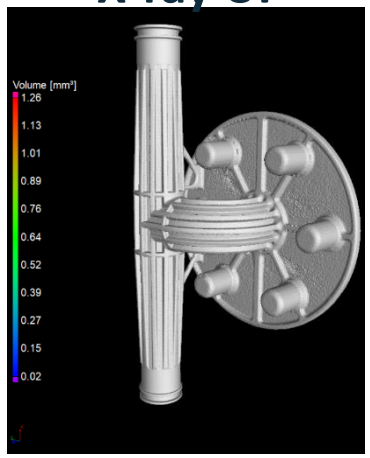
Permeability

Tensile

Vibration



X-ray CT



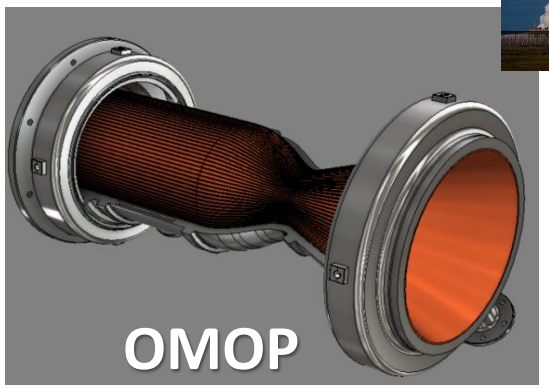
The **HYPROB Project** is funded by **MUR** through the National Aerospace Research Program (**PRORA**).

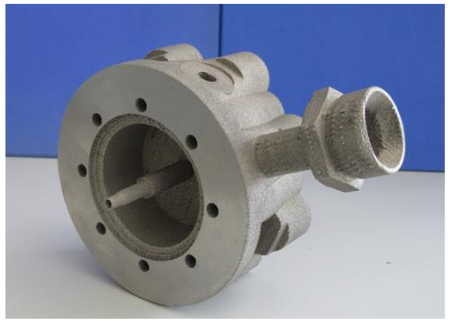
OBJECTIVE: Design, manufacture and testing of ground demonstrator (**L0X/LCH4 engines**) for spatial propulsion system

AM OPPORTUNITIES

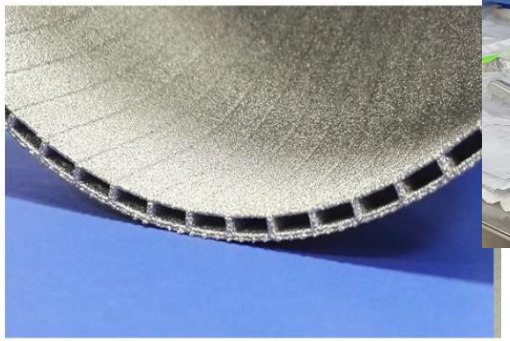
- Reducing Manufacturing costs of critical parts
- Manufacturing of the whole **Regenerative cooled thrust chamber** in Ti6Al4V with a monomaterial and monolithic innovative design (no need for brazing, limited number of parts to be integrated)

ROCKET ENGINE DEMONSTRATOR



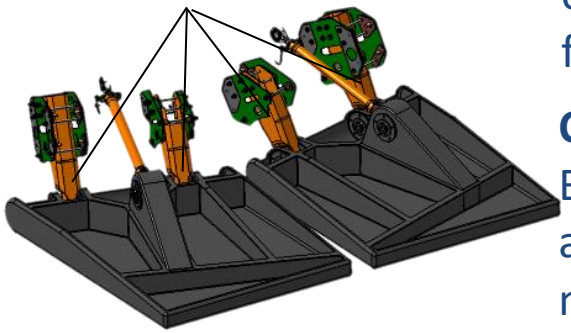


INJECTION HEAD



THRUST CHAMBER MOCK UP

Ti6Al4V Metallic Support



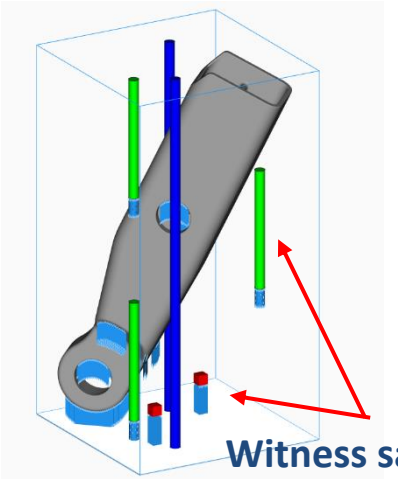
Space Rider (Space **R**eusable **I**ntegrated **D**emonstrator for **E**urope **R**eturn) aims to provide Europe with an affordable, independent, reusable end-to-end integrated space transportation system for routine access and return from low orbit. Its expected maiden flight is 2026.

CIRA is presently in charge of the design, manufacturing and qualification of the Body Flaps Assembly of the **Space Rider** Re-entry Module. Ti6Al4V Metallic attachments between C/SiC Body Flaps with the cold structure have been manufactured by **EBM**.

ESA PROJECT

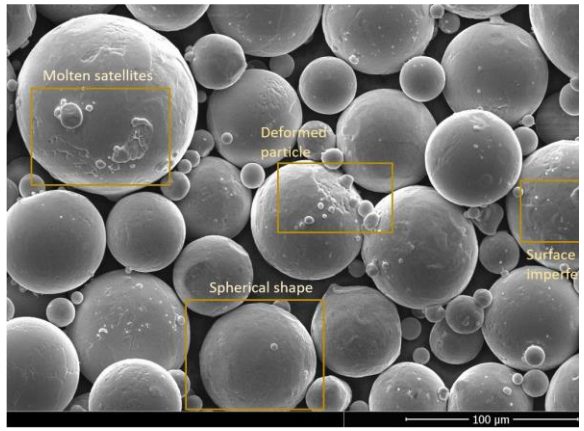
DEVELOPMENT OF THE **QUALIFICATION PROCESS** (ACCORDING TO ESA STANDARD)

Manufacturing



Witness sample

Powder Verification



Material Verification

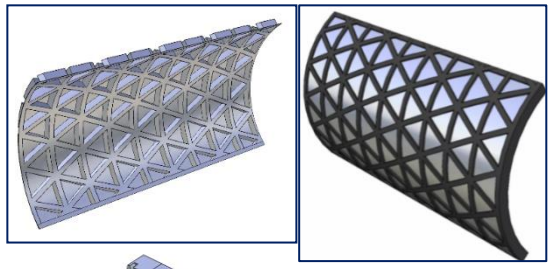
Prototype Verification

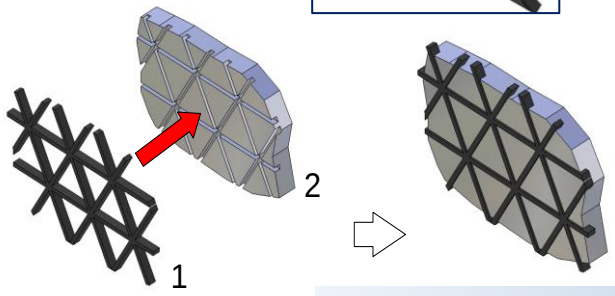
HYBRID (CFRP/TITANIUM) STRUCTURES

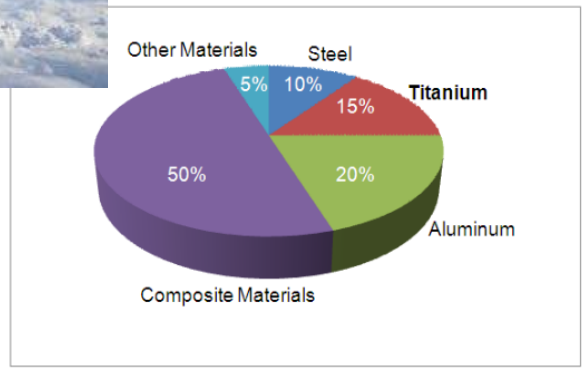
Engineering design, especially in aviation industry, is nowadays driven by the pressing demands for:

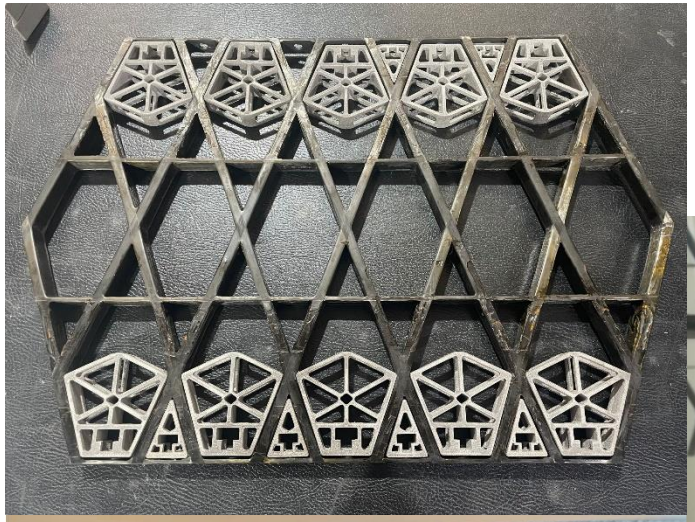
- reducing fuel consumption and the related contaminant emissions, in compliance with the guidelines of international law;
- reducing manufacturing costs related to the technologies and materials;
- reducing manufacturing time, enhancing assembly operations and facilitate maintenance of companies.

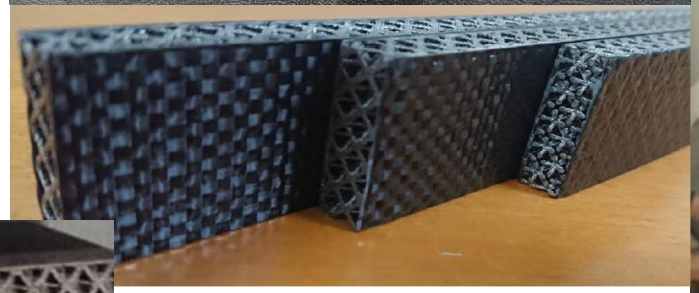
CFRP / Titanium alloy











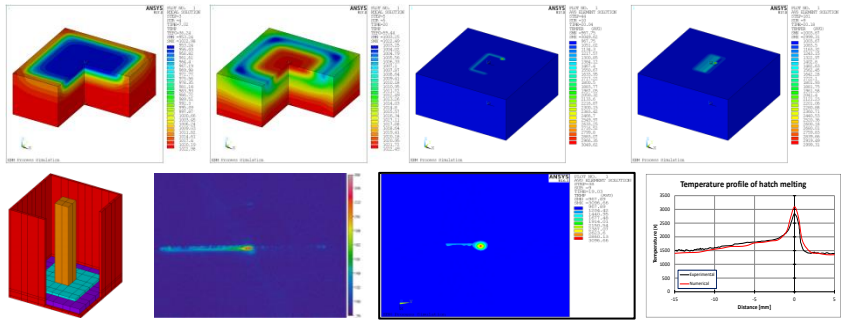
Design | Materials | Process | Post Processing | Qualification

AM allows to put material directly in the right place instead of removing it only where possible!

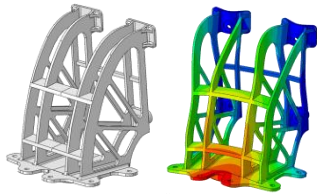
Think additive

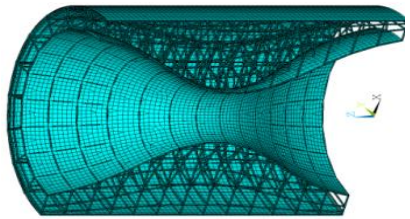
Optimization topology

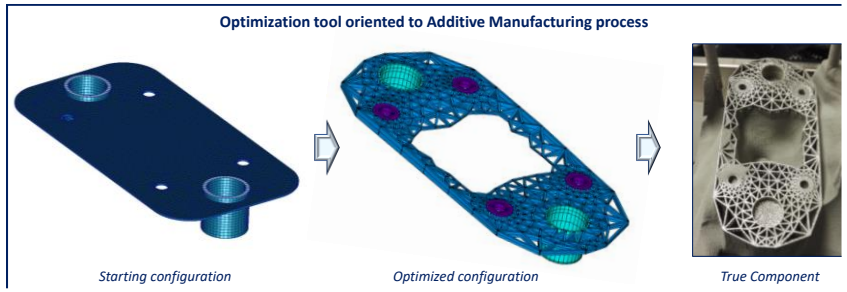
- ***Weight saving***
- ***Improving performances***
- ***Reducing post processing***



Process Simulation to estimate temperature distribution







Design optimization tool for mechanical components, lattice structures and hybrid lattice structure (Ti-CFRP)

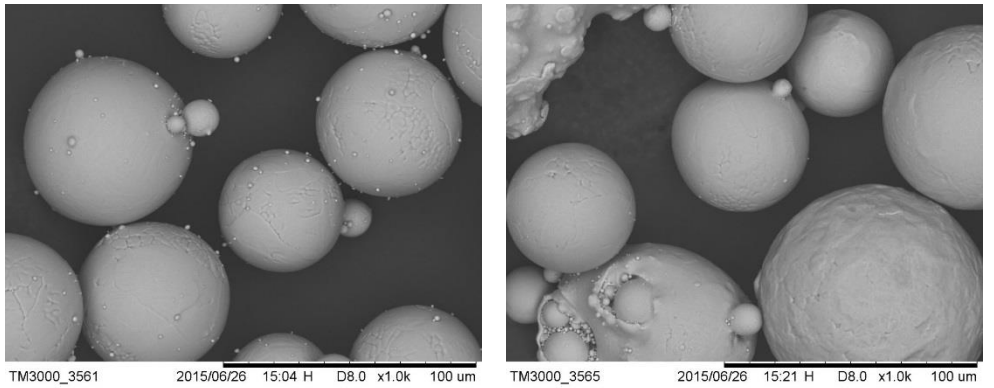
Design | **Materials** | Process | Post Processing | Qualification

Orienting the powder metallurgy to optimize the final properties of the alloys used, studying and qualifying:

- Existing alloys used nowadays only in conventional process not yet in AM
- Blended alloys
- New powders ad hoc developed for AM technologies.

Virgin vs. Recycled

VIRGIN POWDER - 1000X **RECYCLED POWDER - 1000X**

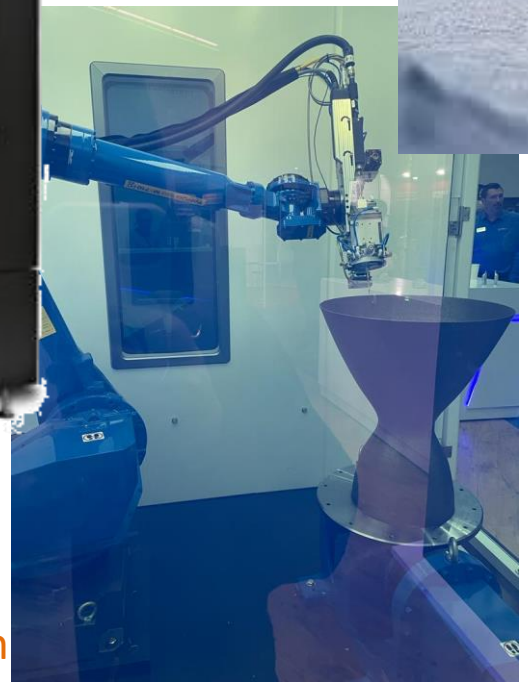


Courtesy of DICMAPI UNINA

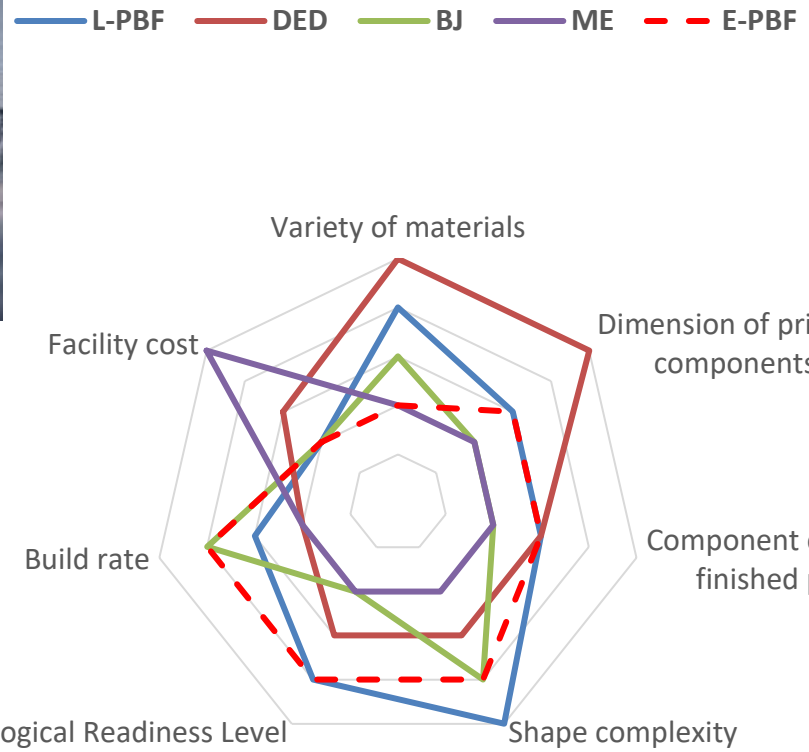
Design | Materials | **Process** | Post Processing | Qualification

EBM: Electron Beam Melting

L-PBF: Laser Powder Bed Fusion

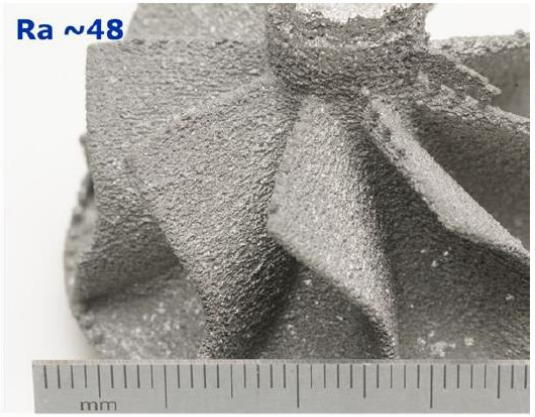


DED: Direct energy Deposition



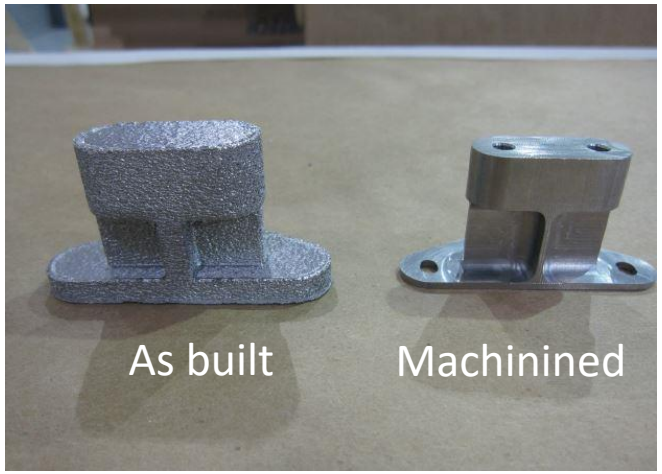
Design | Materials | Process | **Post Processing** | Qualification

Poor surface quality



As EBM processed

Nowaday **machining** provides the best results in terms of dimensional accuracy and surface roughness. BUT IT IS NOT STRATEGIC!!!

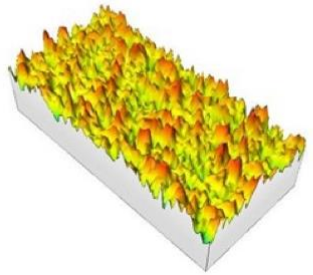


Electrochemical polishing treatment

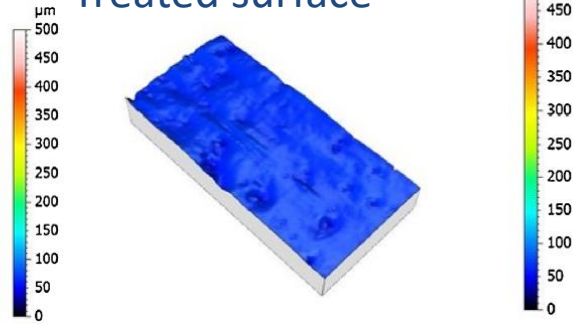
INNOVATIVE SURFACE FINISHING

Chemical surface finishing

As built surface

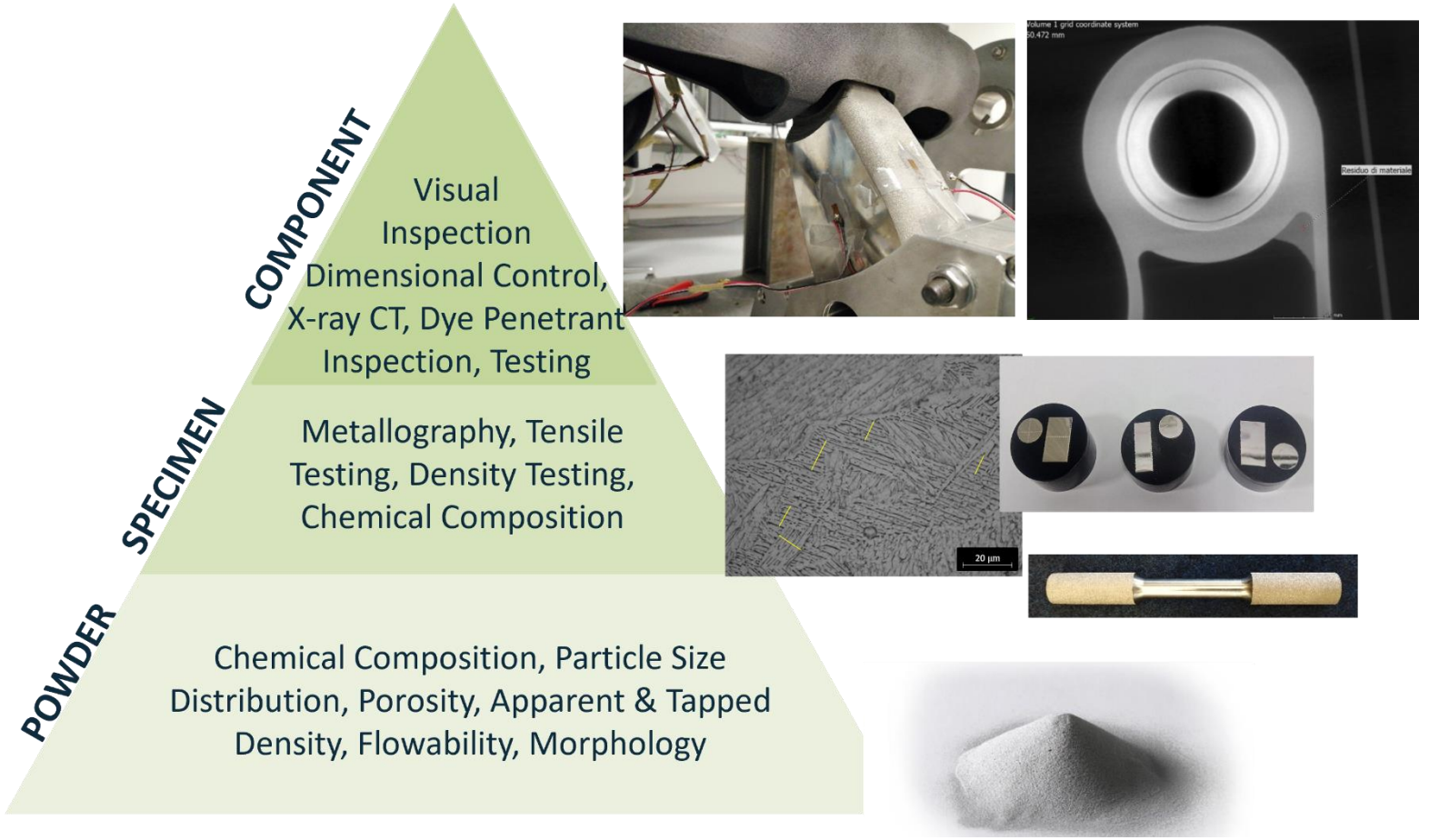


Treated surface



Design → Materials → Process → Post Processing → **Qualification**

Development of the **Qualification Process** (according to ESA Standard)



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- **S. FRANCHITTI, R. BORRELLI, C. PIROZZI,** L. CARRINO, W. POLINI, L. SORRENTINO, A. GAZZERRO, Investigation on Electron Beam Melting: Dimensional accuracy and process repeatability, Vacuum 157, 2018, 340-348, ISSN 0042-207X, DOI: https://doi.org/10.1016/j.vacuum.2018.09.007
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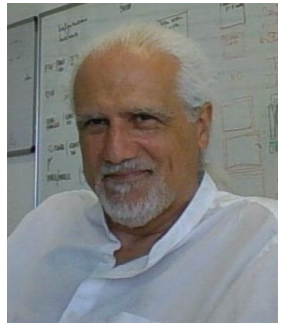

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