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Metal Additive Manufacturing

Challenges & Opportunities

@amplab_unibham #3DMX

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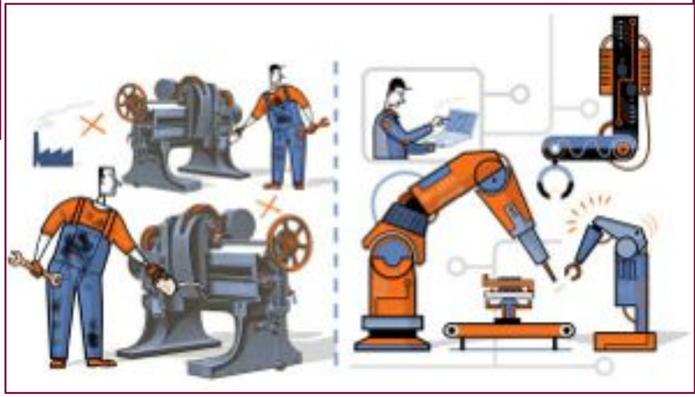
Additive Manufacturing
The Third Industrial Revolution



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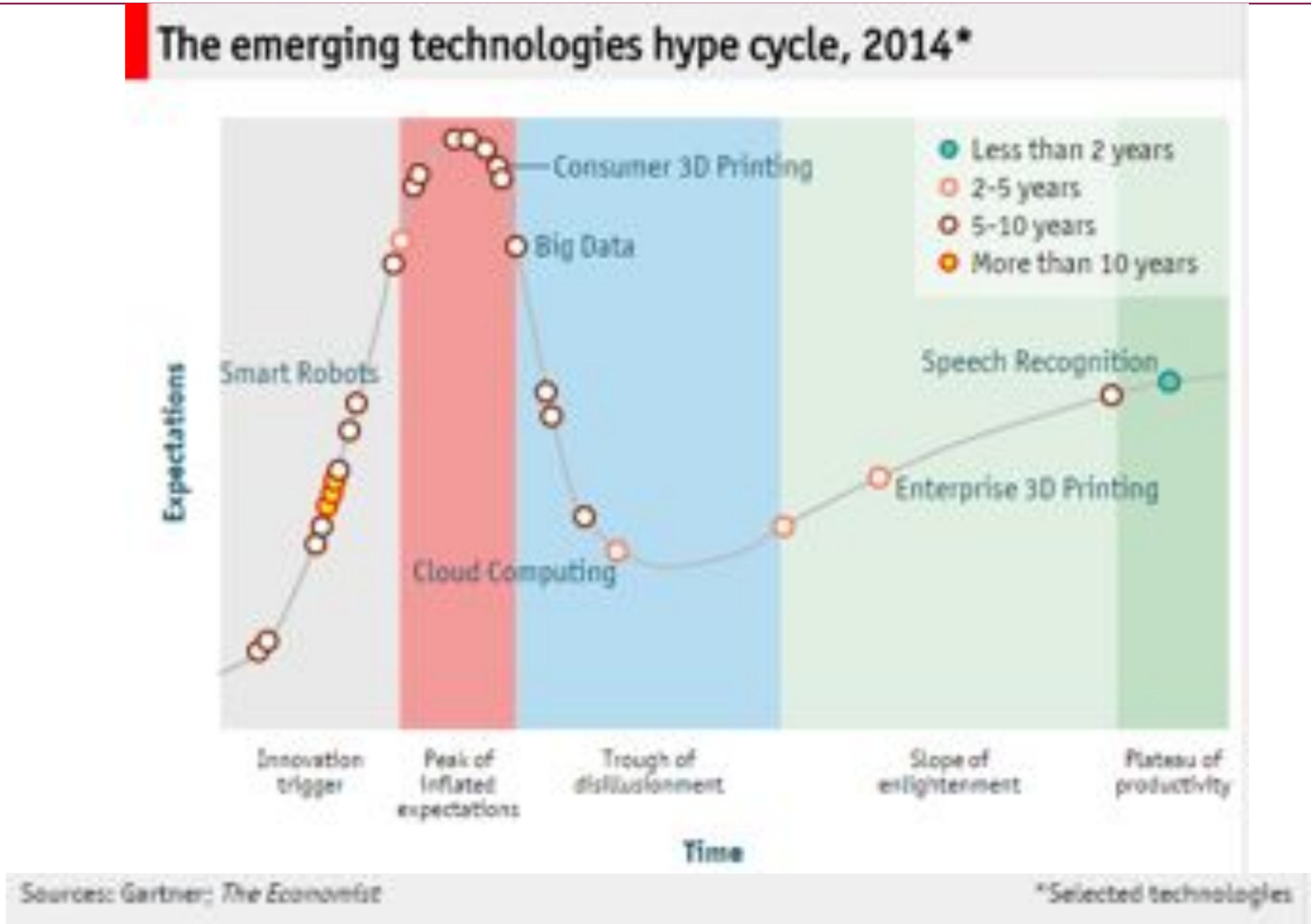
Additive Manufacturing

The Future: Great Expectations. Will It Deliver?

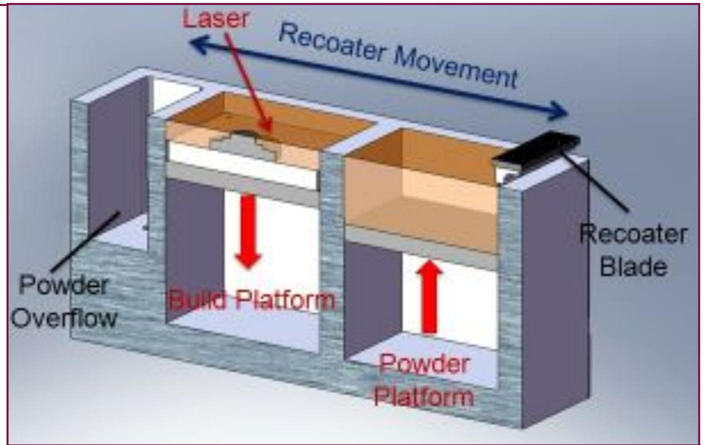


Metal Additive Manufacturing
Different Technologies

□ Powder bed/layer

SLS, SLM, DMLS, EBSM

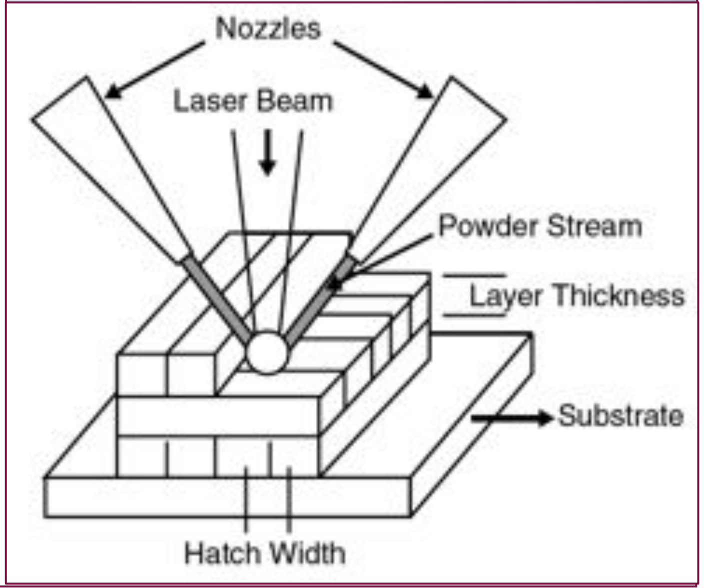
Selective Laser Melting (SLM)
Selective Laser Sintering (SLS)
Direct Metal Laser Sintering (DMLS)
Electron Beam Selective Melting (EBSM/Arcam)



□ Direct deposition

LENS, DLD, DLF, Cladding
WAAM, DLD, EBFFF

Laser Engineered Net-Shaping (LENS)
Direct Laser Deposition/Fabrication (DLD/DLF)
Wire Arc Additive Manufacturing (WAAM)
Electron Beam free-form fabrication (EBFFF)



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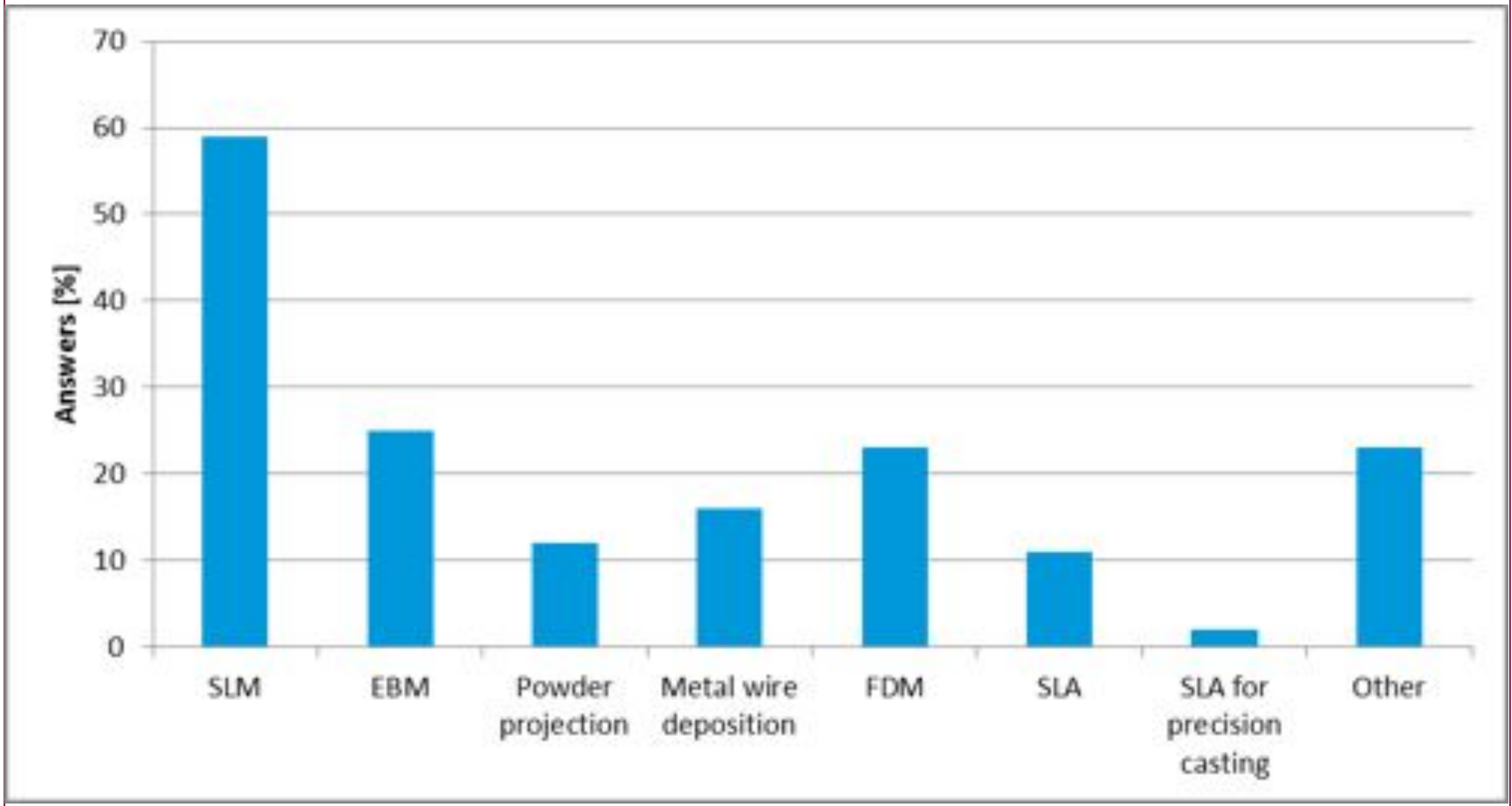
Additive Manufacturing

Distribution of Metal & Plastic Technologies (EU)



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ESA AM Harmonisation, 2015

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Challenges Facing Metal AM

Technology Barriers

- Component **costs are too high** when compared with established manufacturing technology (e.g. casting, forging).
- **Deposition rates** of processes are **too slow**, making a weak business case (depreciation vs. build rates).
- AM machines are **expensive**, **not autonomous**, have **size constraints**.
- **Powders** and resins are **too expensive** for part mass production and in the case of metals not tailored/designed to AM (80% of research focuses on Ti-64, IN718, & AlSiMg Alloys).
- **Insufficient/changing data** to construct business models.
- Product **quality is inconsistent** between batches/machines.
- Lack of in-line **monitoring/control**.
- **Post-processing** (e.g. HIPping, surface finishing, or machining) is always required.

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Challenges Facing Metal AM

In Other Words*…

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*Source Unknown

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Deciding on AM Research Strategy
Weighing the Risks and Opportunities

Companies have to weigh the risks and opportunities in AM research. The decision can be one of the following:

1. **Do nothing; wait and see (e.g. Russia)**.
   - **+:** Investment in metal AM involves a high risk in a technology that has not yet provided a noticeable impact.
   - **-:** The risk of missing an opportunity!
2. Develop an **individual long-term strategy (GE)**
   - **+:** Protect any potential IP, develop a strategy that matches the company's products.
   - **-:** Resources, expensive!
3. Develop strategy involving **academic & industrial (supply-chain) partners (Rolls-Royce, Safran)**:
   - **+:** Sharing the cost, effort, knowledge, and resources.
   - **- :** The risk of not securing the IP.

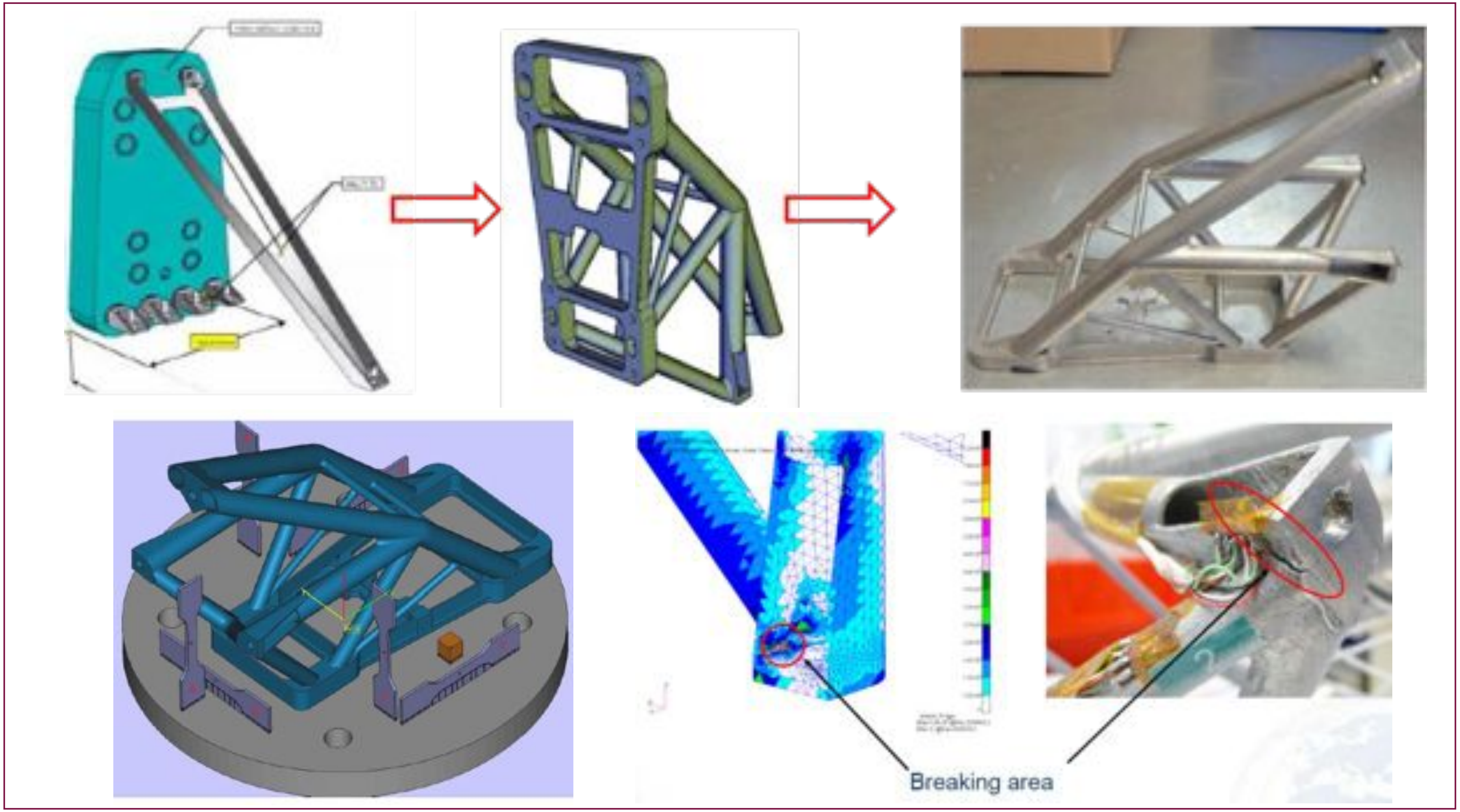
AM Research Strategies
1-The One-Shot Approach

- Identify a component;
- acquire the raw material;
- use the machine manufacturer approved parameters;
- standard post processing (e.g. HIPping)
- perform component testing (in-service conditions, static/ dynamic) and validation (micro CT, mechanical testing); FE simulations.

  - **+:** Cost-effective, rapid TRL/MCRL qualification, marketing/PR advantage (using a trendy technology)
  - **- :** Requires approval following any change (component design, supplier, etc…), not standardised/transferable to other components, redundancy.

AM Research Strategies

Thales Alenia*: One-Shot Approach (Satellites/Low batch)



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*ESA AM Harmonisation, 2015

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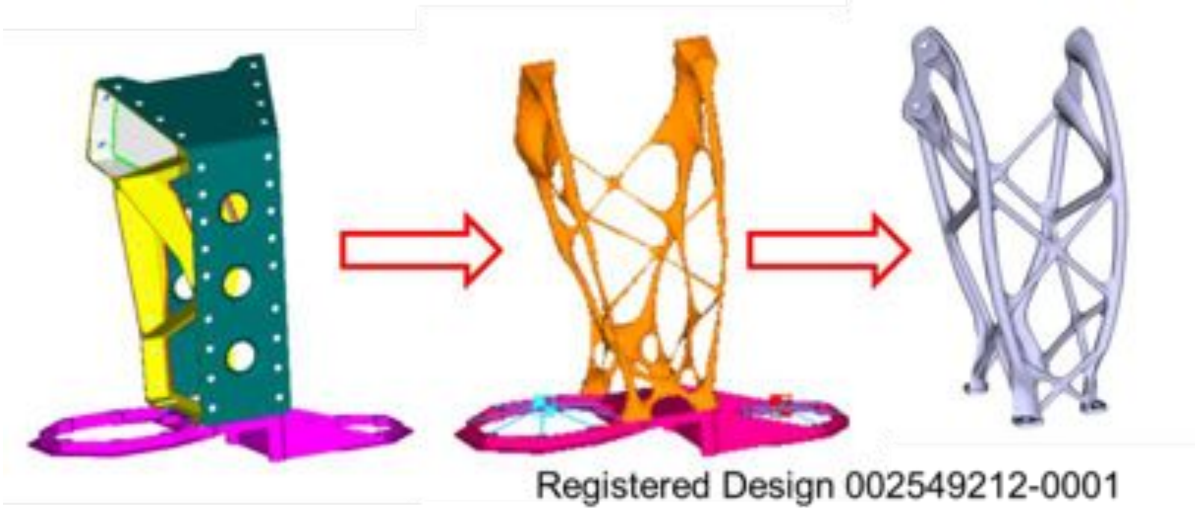
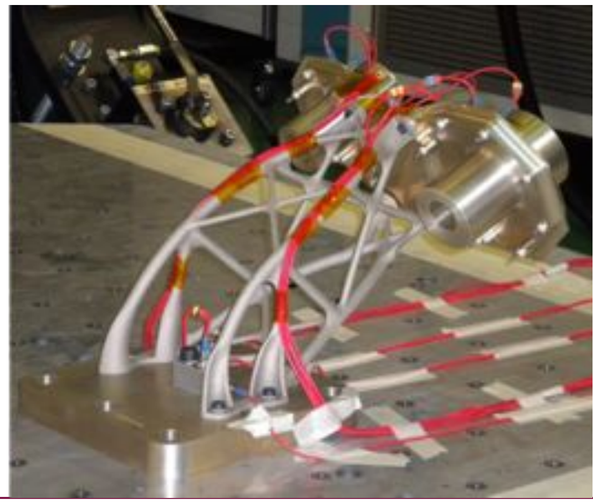
AM Research Strategies

Airbus UK*: One Shot Approach (Satellites/Low batch)





*ESA AM Harmonisation, 2015

AM Research Strategies

2-Multi-Phase Approach (MTU Aero*)

Phase 1: Tooling & Development Hardware

Manufacturing of Tooling,
Development Hardware

Phase 2: Substitution

Cost effective Manufacturing of raw Parts
Substitution of Castings
“Learner” for SLM Process Qualifying

Phase 3: New AM Design

Manufacturing of functional Structures
to reduce Weight and Cost

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*J. Bamberg, K.H. Dusel, W. Satzger , 2014

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AM Research Strategies
3-Standard Qualification Approach

- A comprehensive approach that researches all the process factors (e.g. process parameters, platforms, powder quality & recyclability, post-processing, mechanical properties, FE-simulations/process modelling, etc…
  - **+:** Better understanding of the process, applicability to transfer to various components, standardised.
  - **-:** Expensive, time-consuming.

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AM Research Strategies

AvioGE Standard Qualification (γ-TiAl Blade)

Material:	γ-TiAl
Size:	8 x 12 x 325 mm
Weight:	0,5 kg
Build time:	7 hours / blade

Courtesy of Avio S.p.A.

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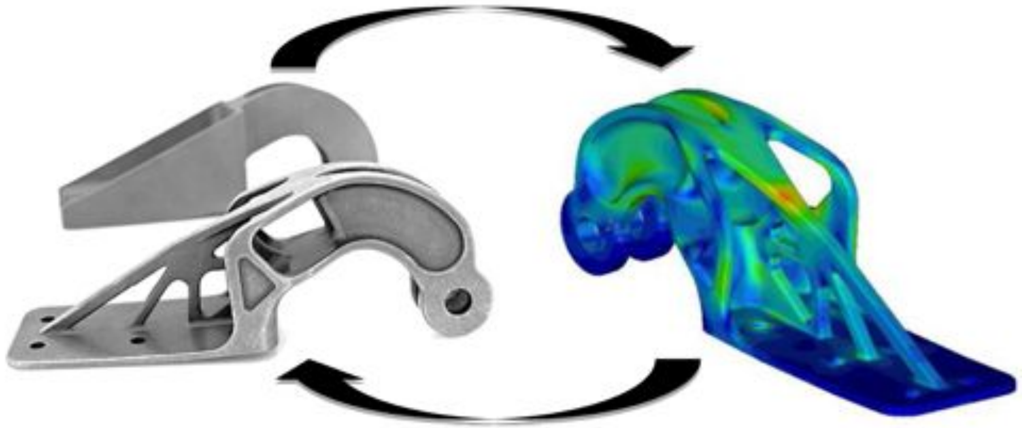
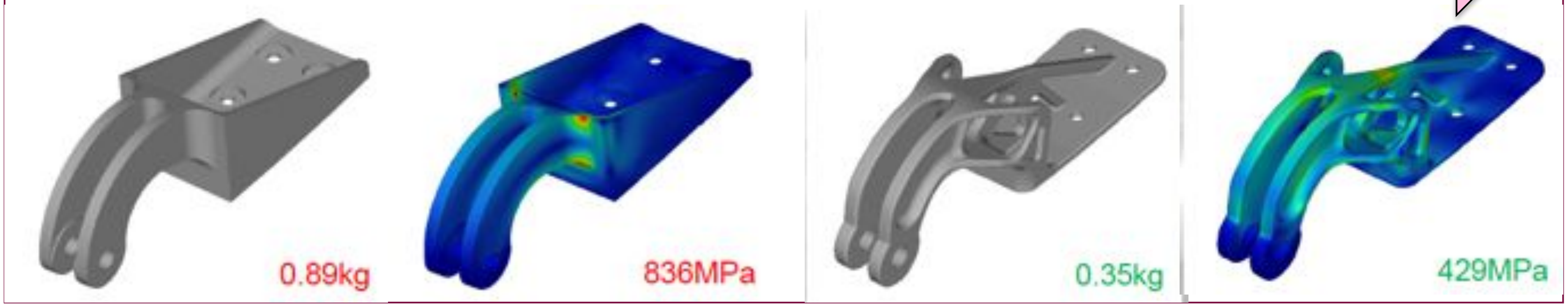
AM Research Strategy
Airbus Standard Qualification (Ti-64)



60% Weight reduction achieved by topology optimisation



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*Myers, 2011

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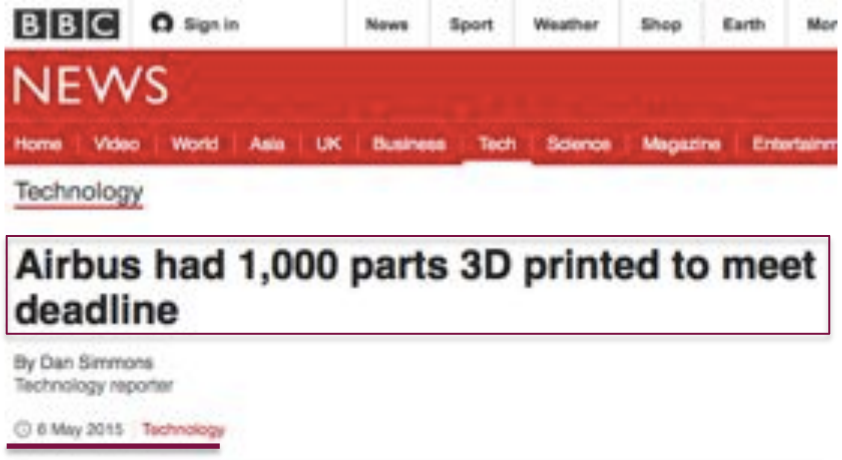
AM Research Strategies

Airbus (Business Advantage of Standard Qualification)



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Technology

Airbus had 1,000 parts 3D printed to meet deadline

By Dan Simmons
Technology reporter

6 May 2015 | Technology

A350 XWB is to have more than 1,000 3D-printed parts

AM Research Strategies
Standard Qualification AM Products

GE Aviation Leap Engine Nozzle
10^5 parts required by 2020
3% wt. reduction
2.5 x endurance
Cost (mass production)?!

Rolls-Royce Trent XWB OGV
Vanes made by Arcam + Welded
Test flight in 2015
Properties? Weight reduction?
Cost (mass production)?!

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Addressing the Challenges

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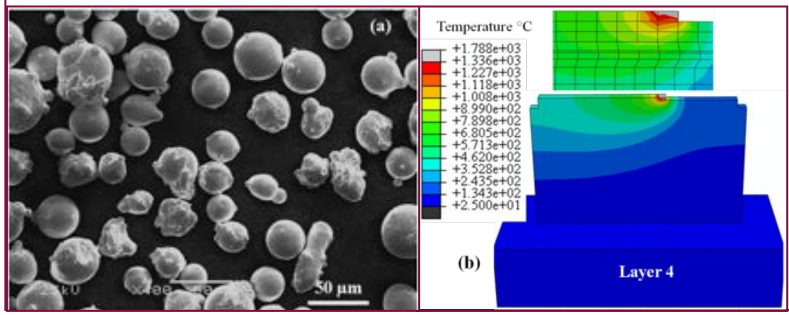
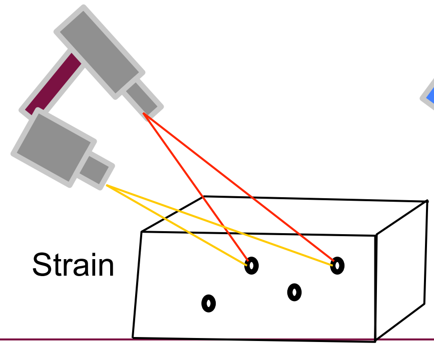
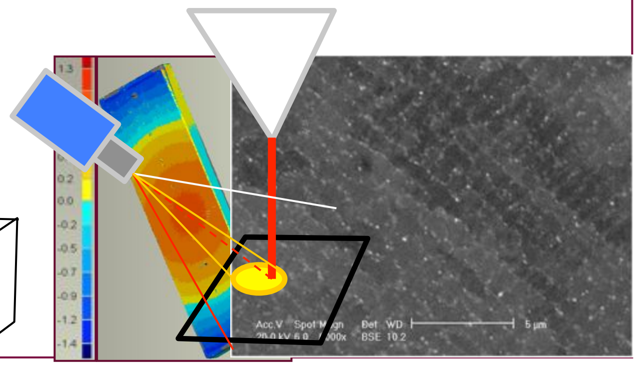
AMPLab
CONCEPT
SLM
EPSI

Metal Additive Manufacturing
Research Challenges Investigated by UoB/AMPLab

- Impact of powder feedstock (consistency, quality, performance, repeatability, and security) on properties.
- Process modelling using computationally non-CPU intensive codes.
- Non-destructive evaluation, in-situ monitoring, 3D scanning, Micro CT.
- Residual stress: measurement, management and control.
- Microstructure-Property control (e.g. property optimisation).
- Surface finishing and post-processing (e.g. HIPping).







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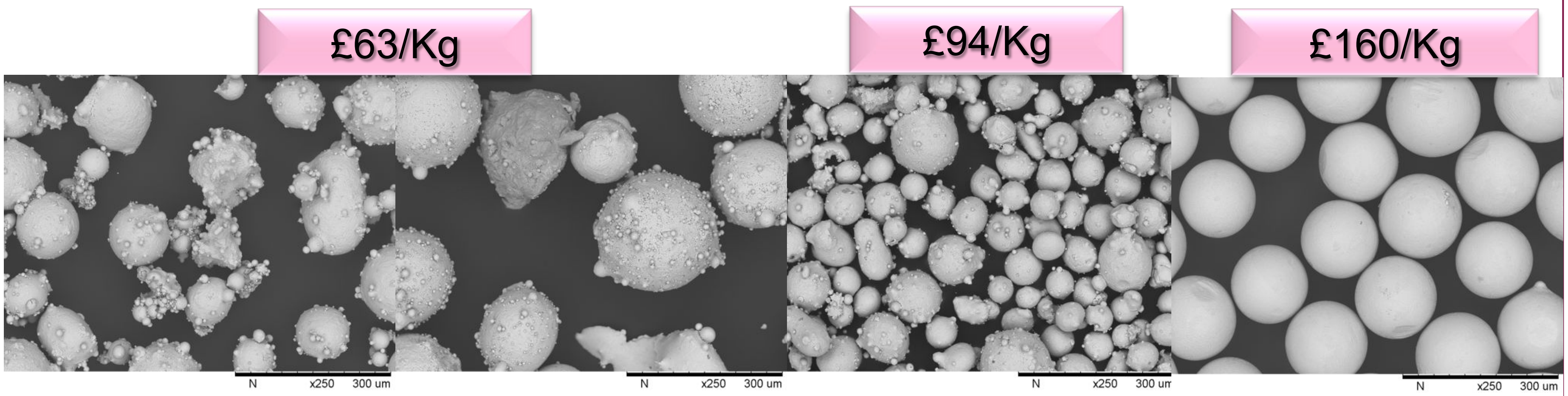
Addressing AM Research Challenges

Powder Quality & Impact on Properties

- Significant disparities can exist in powder morphology, flowability, apparent/tap density, chemistry (N,O,C), etc….
- Repeatability/consistency/recyclability of powder are concerns.
- Limited data is available on the impact of powder characteristics on the product performance.



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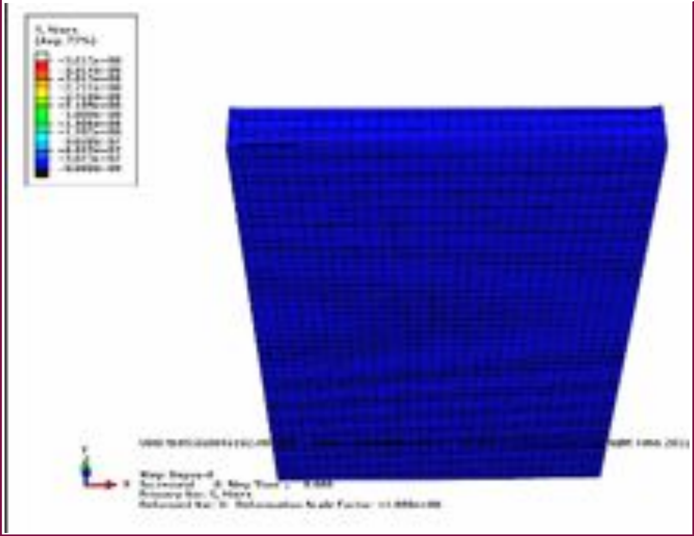
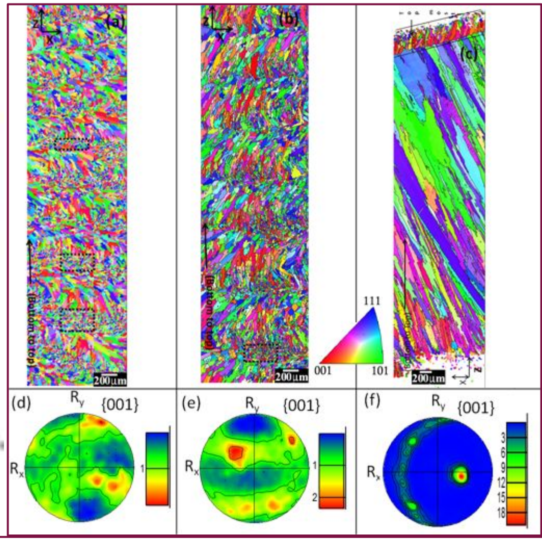
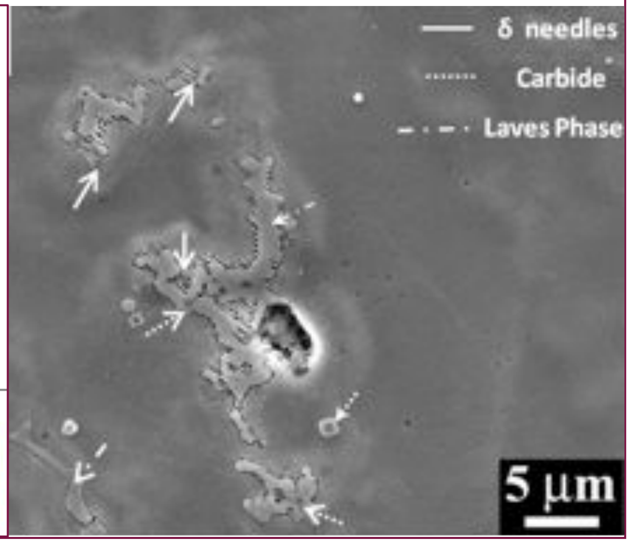
Addressing AM Research Challenges

FE Modelling of Residual Stress & Temperature

- A useful tool to predict the temperatures, microstructural development, residual stress, and properties.
- The challenge is to create models that produce 'reasonable' predictions, with limited 'fudge factors' (fitting parameters), and low computational time.







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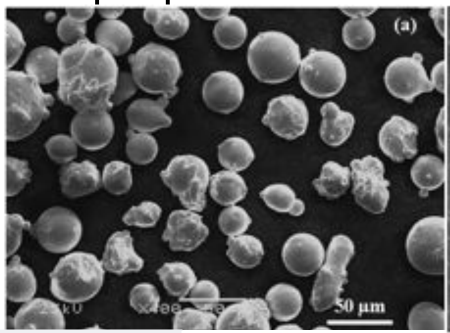
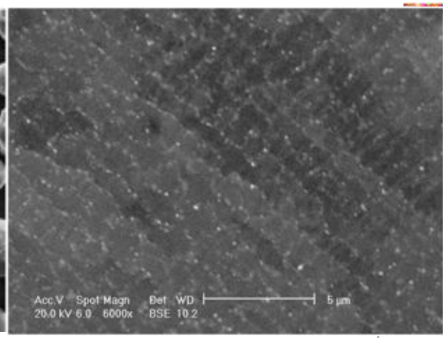
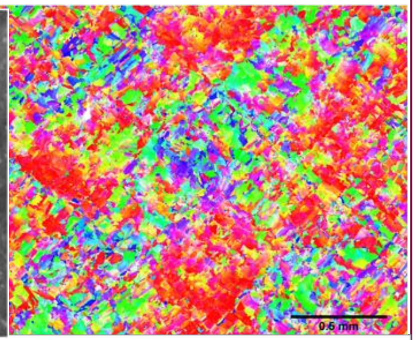
Addressing AM Research Challanges

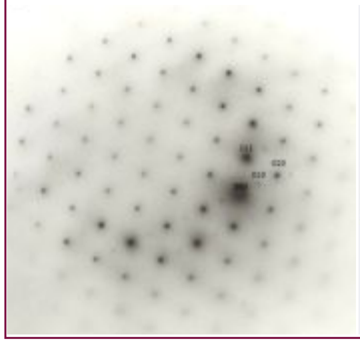
An Holistic Approach to Product Qualification

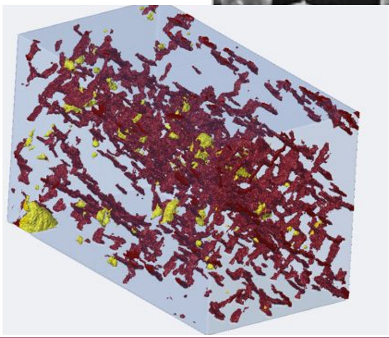
- **Aim:** To establish SLM processing route for aerospace components from the high temperature Ni-superalloy CM247LC
- **Main Findings:**
  - Understand the influence of the process parameters, and post-processing heat treatments, to minimise the defects, improve microstructure and maximise mechanical properties.

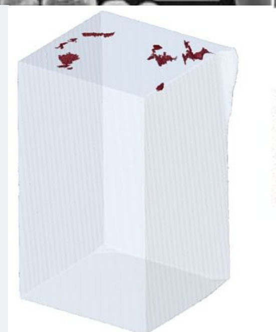


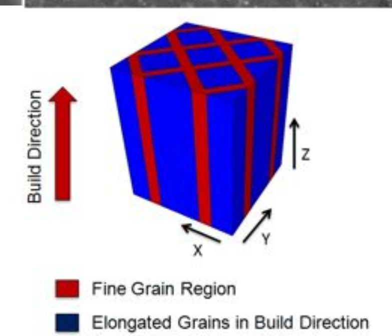


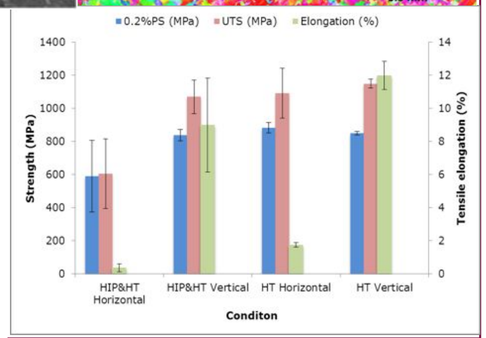












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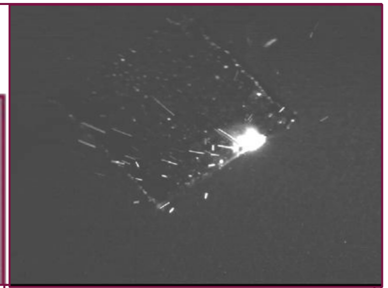
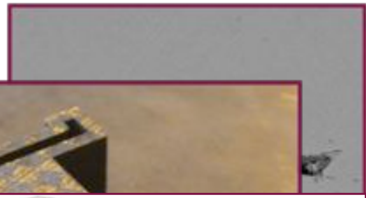
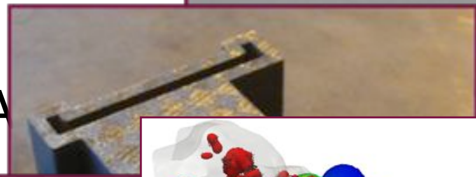
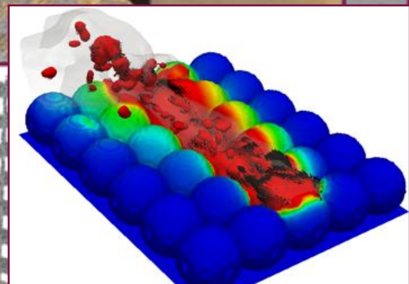
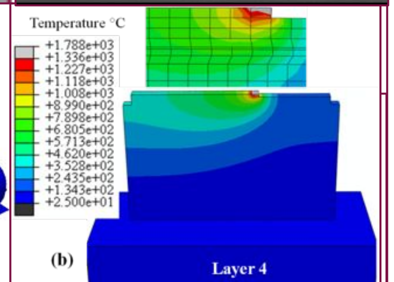
Additive Manufacturing
Addressing the Challenges

- Defect formation, characterisation & mitigation
- Post-processing (using HIPping)
- Tooling development using AM
- Micro and macro modelling of A
- Multi-functional AM
- Microstructural control
- Large scale deposition

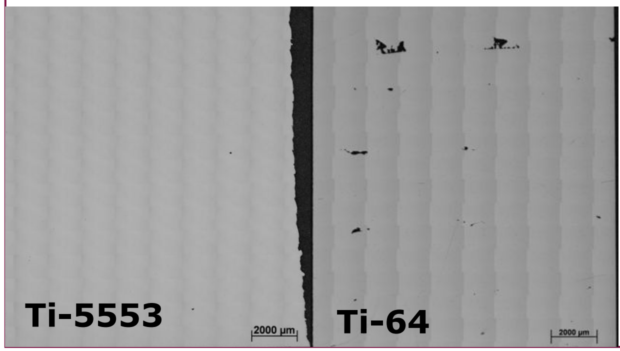




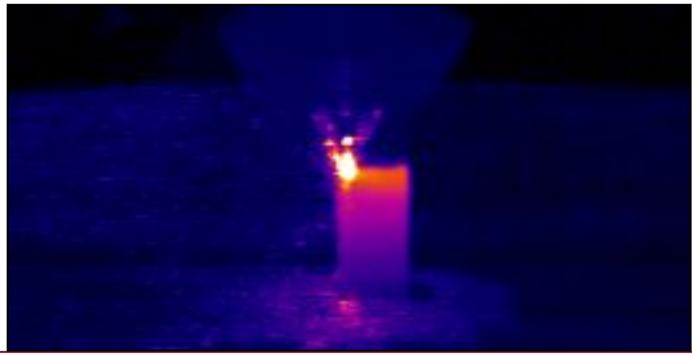



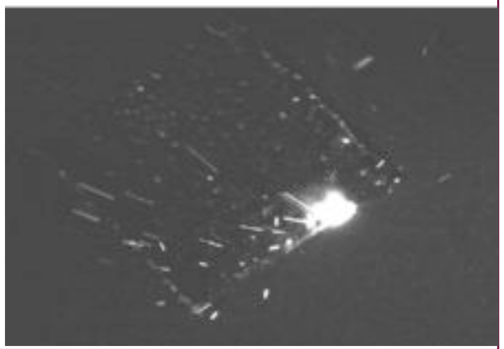
Additive Manufacturing

Key Technology/Materials challenges

- Alloy development for ALM.
- Physics-based tool path (heat source) optimisation.
- Laser-powder interaction: physics and thermodynamics.
- Difficult-to-ALM materials: tungsten, single crystal Ni-superalloys, refractories, Al-alloys, gum metal, SMAs, silicides, composites, Ni-superalloys, γ-TiAl, etc…
- Novel applications: sensors embedding, composites, etc…







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Additive Manufacturing

Research Roadmap

Process Monitoring & NDE

- Temperature measurements
- Strain measurement (strain sensors, image correlation, live GOM).
- Defect identification (ultrasonic sensors, phased array, image analysis of melt pool).
- Load measurements (in fixtures)

Modelling

- Tool path optimisation (TPO) for geometrical consistency
- TPO based on thermal fields simulation
- TPO using numerical optimisation methods

Product Requirements

- Low Distortion
- Defect-free (porosities, lumps)

Process Parameters

- Laser power
- Scan speed
- Laser pulsing
- Scan speed
- Laser preheating
- Layer thickness

Adaptive Thermal Management

- Thermal measurements
- Controlled heating/cooling
- Secondary laser stress relief/heating

Process Control & Analytics

- Real-time process analytics.
- Feedback control on process parameters.
- Self-adaptation based on monitoring feedback.

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Summary & Conclusions

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Conclusions
Author's View

- There are several models for a research strategy development in Additive Manufacturing.
- The MTU's 3-phase strategy provides a balanced approach for AM technology adoption.
- The standard qualification approach develops knowledge & standards that are applicable to various components in the business, provided that the business need exists.
- The one-shot approach may help the company score immediate business/marketing image target.
- Technology challenges can only be addressed via a balanced modelling & experimentation approach.

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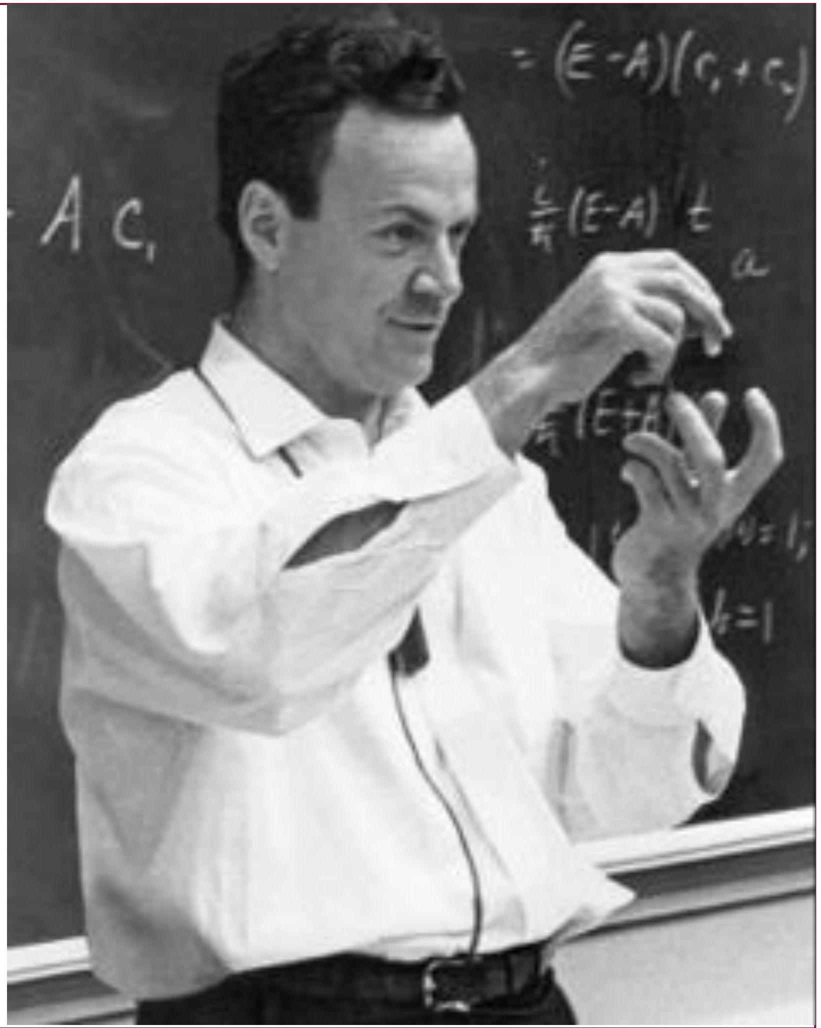
Technology Success

"For a successful technology, ***reality*** must take precedence over ***public relations***, for nature cannot be fooled."

Richard Feynman, 1986



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Collaborations & Funding

2011-2015

SAFRAN Microturbo

Rolls-Royce

EPSRC

ALSTOM

esa

Innovate UK Technology Strategy Board

TWI

GKN AEROSPACE

广东省工业技术研究院

CLEANSKY Joint Technology Initiative for Aeronautics & Air Transport

SEVENTH FRAMEWORK PROGRAMME

ITP GRUPO Industria de Turbo Propulsores, S.A.

CCFE CULHAM CENTRE FOR FUSION ENERGY

IHI

M&I MATERIALS

dstl

controls and data services Part of the Rolls-Royce Group

JM Johnson Matthey

mtc Manufacturing Technology Centre

MINISTRY OF DEFENCE CENTRE FOR DEFENCE ENTERPRISE

MBDA MISSILE SYSTEMS

TRUMPF CONCEPTLASER

MEGGITT

BAE SYSTEMS

SAFRAN Messier-Bugatti-Dowty

CATERPILLAR®

A*STAR Advanced Remanufacturing and Technology Centre

References

- Moataz Attallah

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Questions?

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