Additive Manufacturing – A European Perspective

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Additive Manufacturing Platform Committee

Materials Joining and Engineering Technologies

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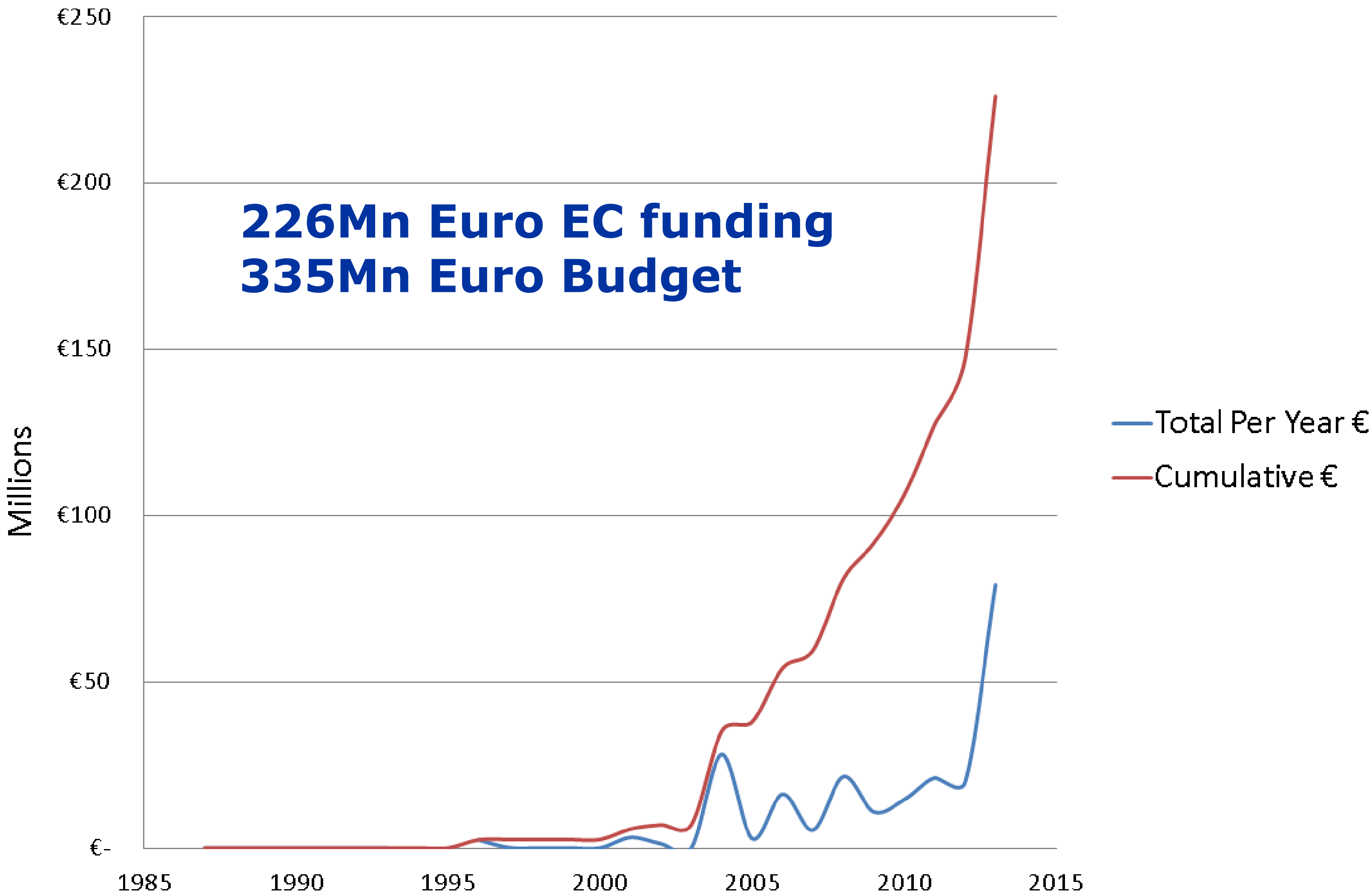
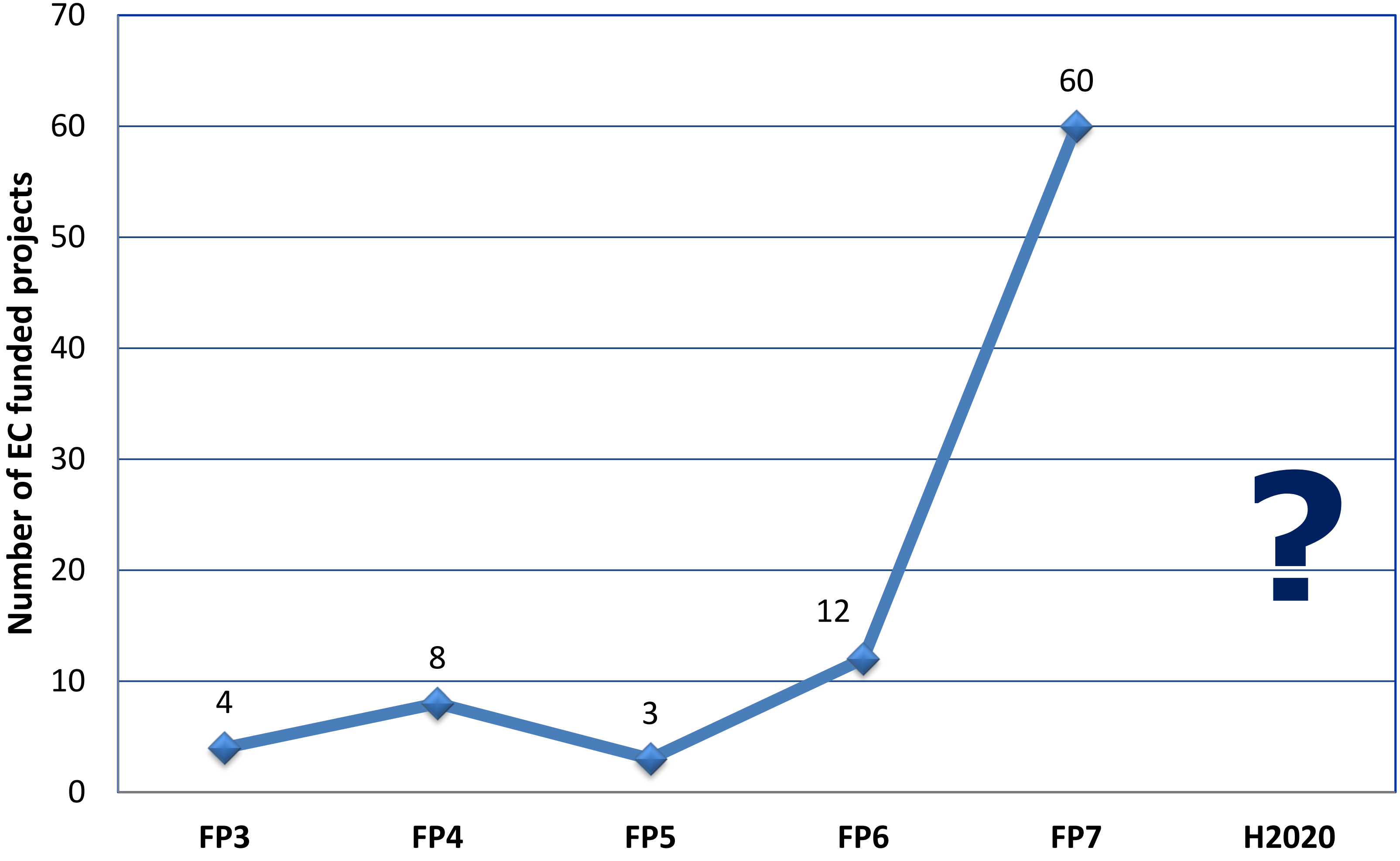
EC Funding of AM



AM projects in EC Frameworks



Typical Project

- Range from 100k Euro to 10Mn Euro Grant

- 5Mn Euro Grant
- Three Large Companies
- Four Research Entities
- Four SME's
- Material supply, design, processing, NDT, validation etc….

EC AM Projects

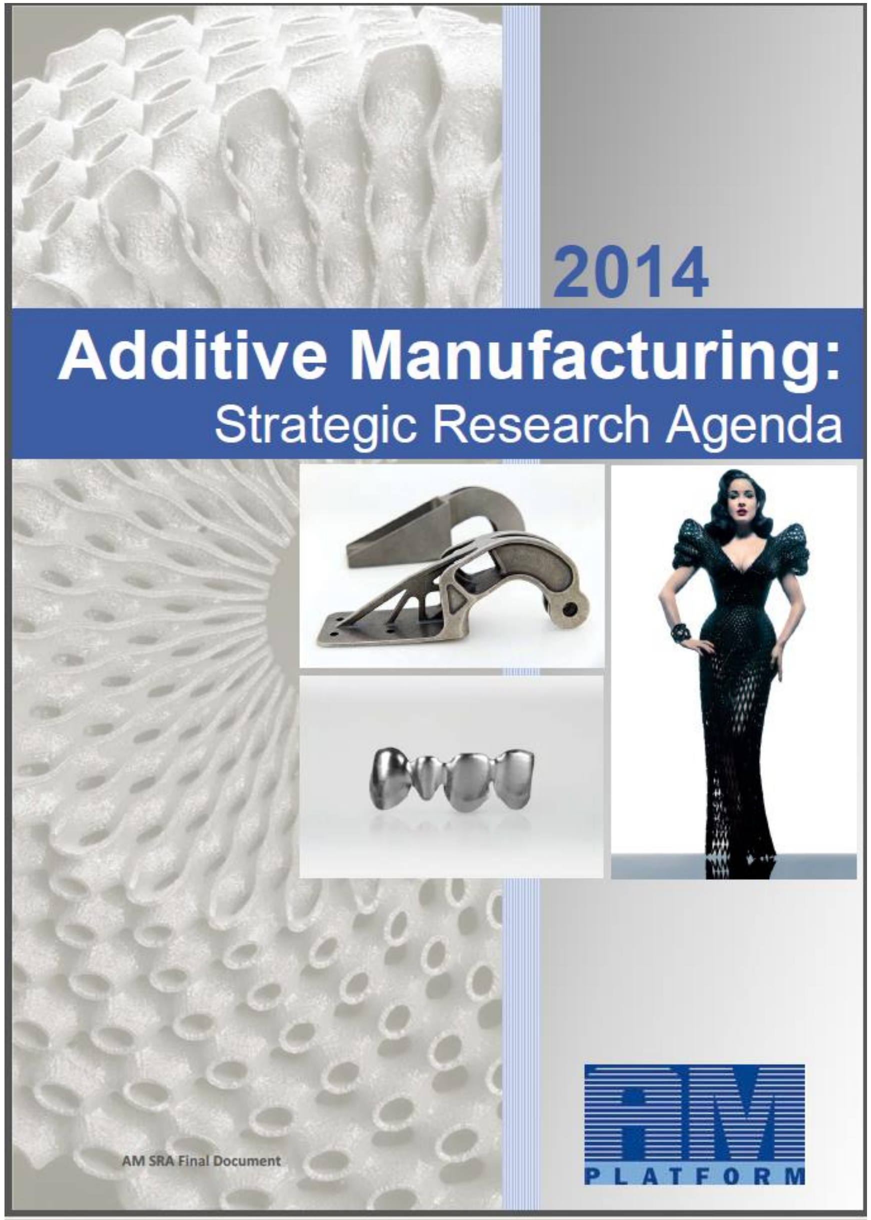
VITAMIN
PHIDIAS
DIGHIRO
FLOWMAT
AEROBEAM
M&M'S+
VINDOBONA
D-FOOTPRINT
PRINTCART
INLADE
RAMA3DP
SASAM
ADM-ERA
PRINCIPLE
METAL-PRINT
SIMCHAIN
RRD4E2
AEROSIM
FLEXRAP

HIRESEBM
INTRAPID
FASTEBM
IMPLANT DIRECT
NOVELSCAFF
DIGINOVA
SHAPEFORGE
MALT
IDAMME2
KARMA
RAPIDOS
BIO-SCAFFOLDS
M&MS
RC2
FLEXFORM
RAMATI
PRIME
NAIMO
RAPROMO
DERP
VITAMIN

MAID
PHOCAM
IRRESISTIBLE
SMARTLAM
MANSYS
AMCOR
FABIMED
STEPUP
IC2
MICROFLUID
HIPR
NEXTFACTORY
3D-HIPMAS
HI-MICRO
CORENET
COMPOLIGHT
DIRECTSPARE
CUSTOM-FIT
HYDROZONES
AMAZE

OPEN GARMENTS
OPTICIAN2020
PLASMAS
A-FOOTPRINT
LIGHT-ROLLS
FANTASIA
INTERAQCT
OXIGEN
PILOTMANU
NANOMASTER
REPAIR
IMPALA
MERLIN
CUSTOM-IMD
ADDFACTOR
CASSAMOBILE
EUROFIT
MULTILAYER
PERFORMANCE
ARTIVASC 3D

TWI


2014
Additive Manufacturing:
Strategic Research Agenda
AM SRA Final Document
AM PLATFORM

Background

- Dr Emma Ashcroft - TWI
- Pentti Eklund - VTT
- Frits Feenstra - TNO
- Magi Galindo I Anguera - Leitat
- Martin Baumers - Nottingham University
- Anna Hoiss - DSM
- Olivier Jay - Teknologisk Institut
- Dr.-ING Eric Klemp – DMRC
- Jörg Lenz - EOS
- Prof. Gideon Levy - TTA
- Dr Phil Reeves - Econolyst Ltd
- Martin Schaefer - Siemens AG
- Jan Sehrt - University of Duisburg
- Dipl.-Wirt.-Ing. Marina Wall - Heinz Nixdorf Institute, University of Paderborn
- Dr Robert Scudamore - TWI
- Dr Tom Craeghs – Materialise
- Prof. D Wimpenny - MTC

Over fifty reference documents from the AM community and beyond
EU focus and more country specific

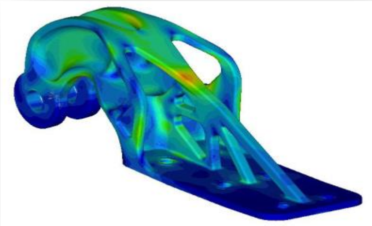
Benefits

- Design freedom
- Cost – Material utilisation, energy, lead time, tooling
- Customisation – Process flexibility
- Increased part performance
- Light weighting
- New products
- Localised manufacturing – EU job creation and retention and Economic Growth

Main Industrial Sectors

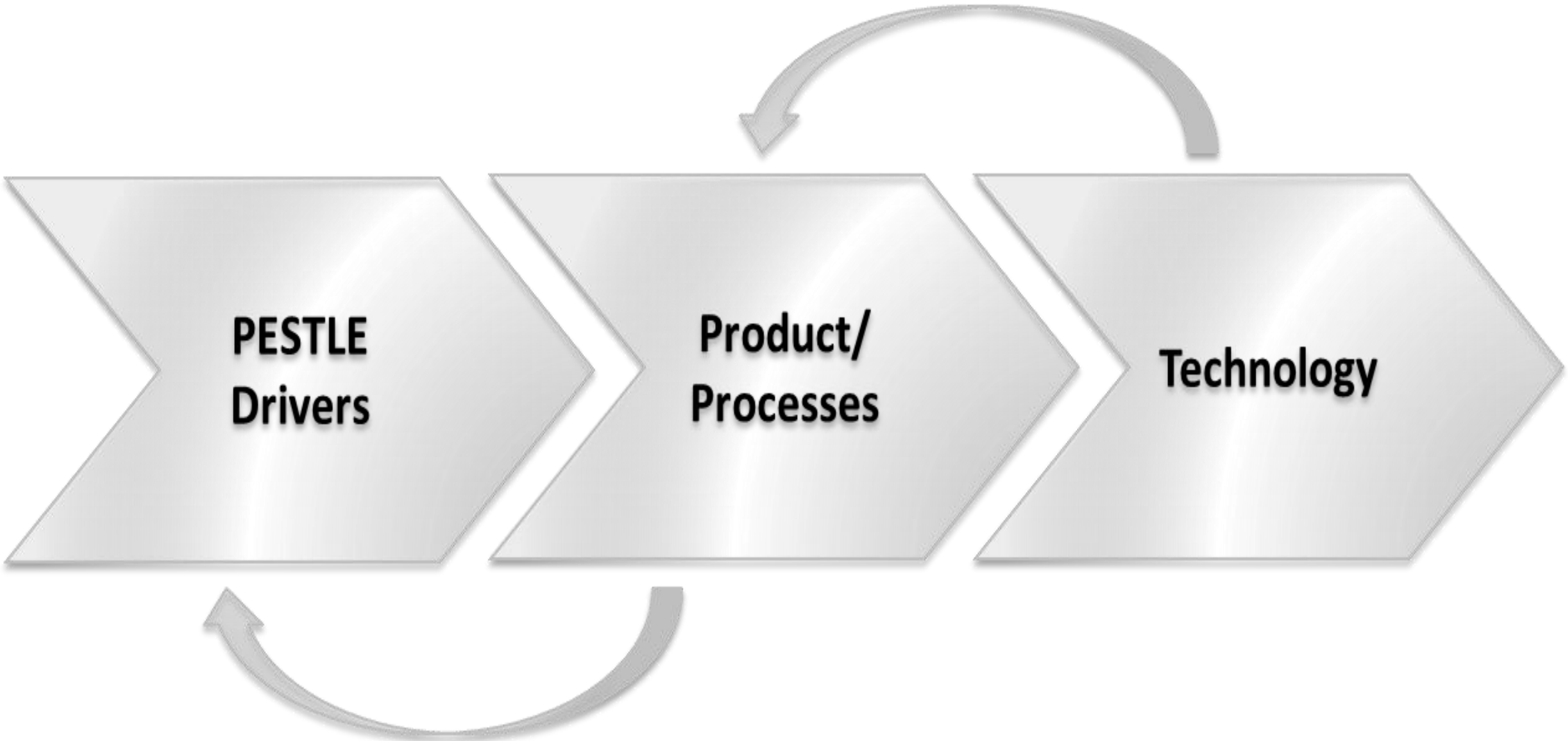
- Medical and Dental
- Aerospace
- Automotive
- Consumer
- Electronics

- Niche areas
- New markets






Approach



Technology Readiness Level

Programme Phase	Level	State of Development
Phase 3 Production Implementation	9	Fully production capable process qualified on full range of parts over extended period (all business case metrics achieved)
	8	Fully production capable process qualified on full range of parts over significant run lengths
	7	Capability and rate confirmed via economic run lengths on production parts
Phase 2 Pre-production	6	Process optimised for capability and rate using production equipment
	5	Basic capability demonstrated using production equipment
Phase 1: Technology Assessment and Proving	4	Process validated in laboratory using representative development equipment
	3	Experimental proof of concept completed
	2	Applicability and validity of concept described and vetted, or demonstrated
	1	Process concept proposed with scientific foundation

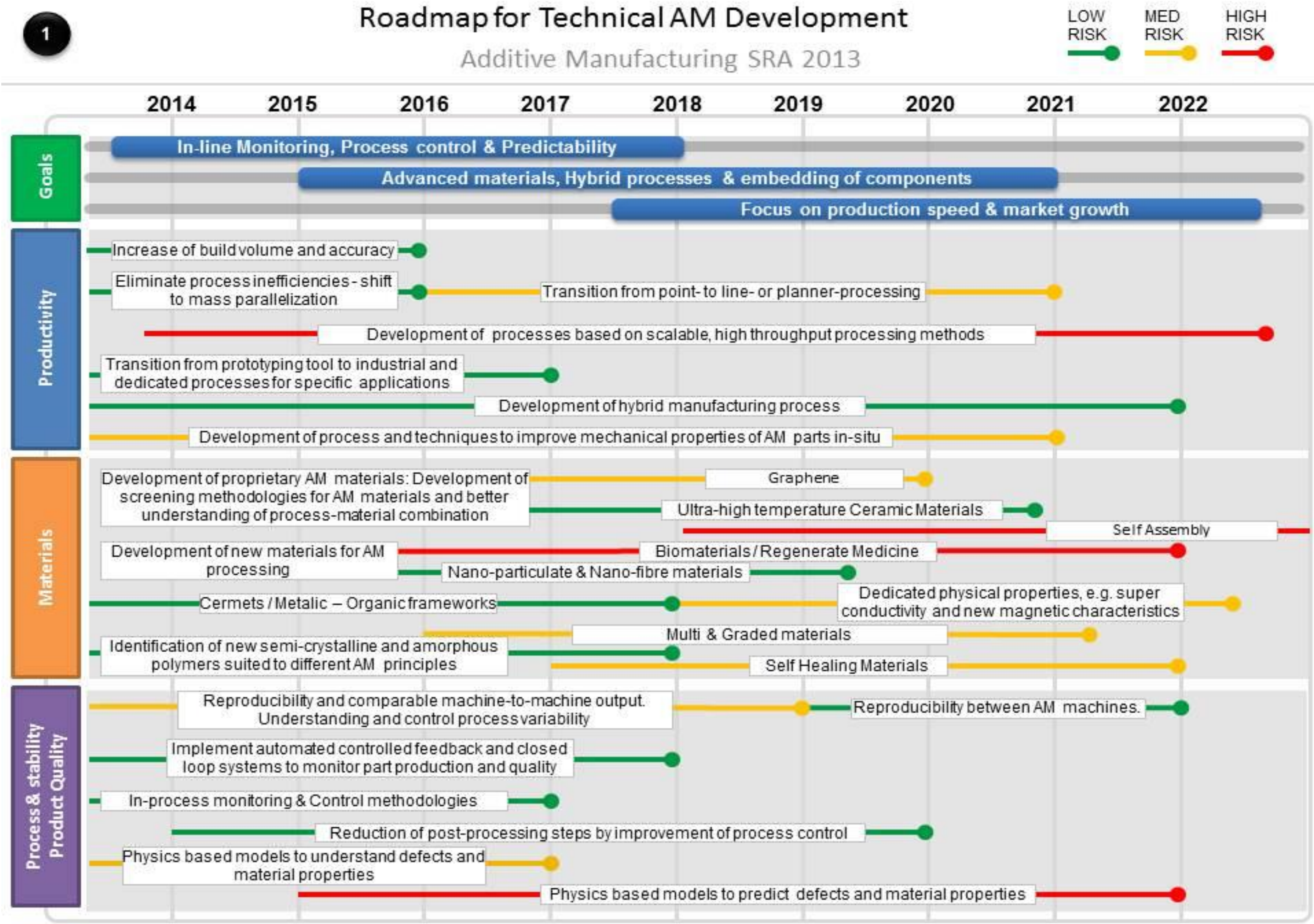
Recommendations

Productivity	
Increase build-speed, possibly through new approaches to scanning or sources of energy.	Decrease the time to create each layer, the overall time between layers, and start-up and shut-down time.
Support higher volume production, possibly through enabling batch consistency and methodologies for consistent materials supply.	Develop methodologies for measurement of AM products.
The development of new/advanced AM machines e.g. machines with multiple lasers.	
Process Stability	
Increase material processability, quality and performance.	Develop methodologies for 'Right first time' processing.
Increase control of process tolerances.	Develop tools for better temperature management during processing.
Improve surface finish of processed parts.	Improve geometrical stability.
Improve process control and monitoring.	Analyse energy consumption and development of methodologies for its reduction.
Further develop lasers with improved efficiency and control.	Develop multi-material manufacturing for AM technologies.
Reduce residual stresses.	Increase software utilisation.
Analyse stability of the AM process in order to make improvements to AM systems that will allow production components to be produced with required properties.	

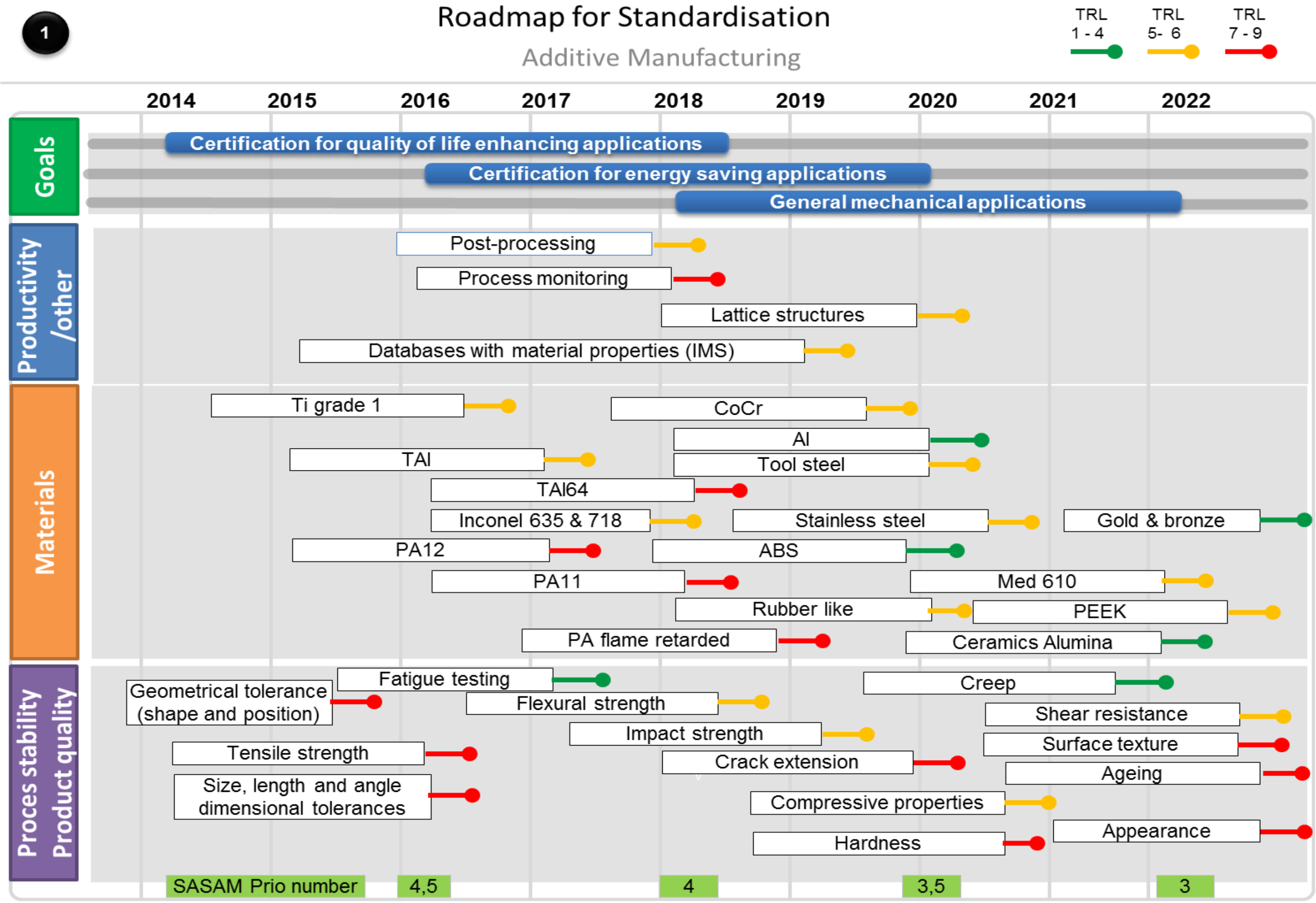
Recommendations

Other	
Global collaboration in the area of AM would be beneficial particularly between EU and USA.	Identification of applications and work with end-users to understand the business case for using AM over other manufacturing routes.
Mechanisms for taking a product into production e.g. taking proven concepts at TRL4 and moving them to TRL 7 to 9.	Supply chain development, from material supply, reliable AM systems to post-processing.
Functionally graded structures in terms of design or material.	More consideration to the value proposition for AM e.g. digital data.
The creation of assemblies using AM.	Establishment of bio-tissue engineering using AM.

Timescales and Risk



Standardisation Roadmap



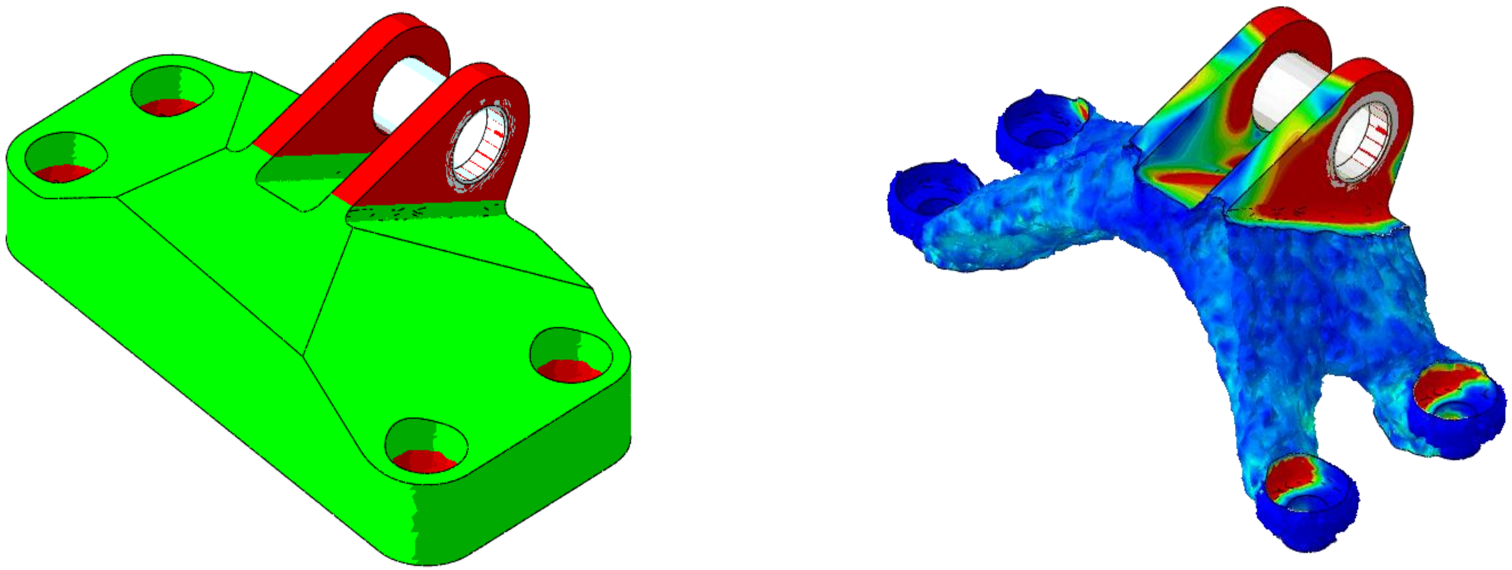
Focus Areas

- Design freedom
- Topology optimisation
- Customisation
- Raw material quality
- Equipment design
- Process capability
- Process stability
- Process flexibility
- Process modelling

Focus Areas

- Material properties
- Residual stress
- Non-destructive testing
- Surface finish
- Dimensional tolerances
- Standardisation
- Supply chain initiatives
- Access for SME’s

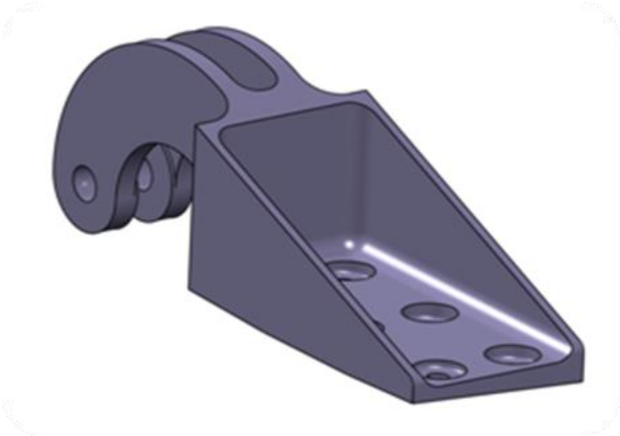
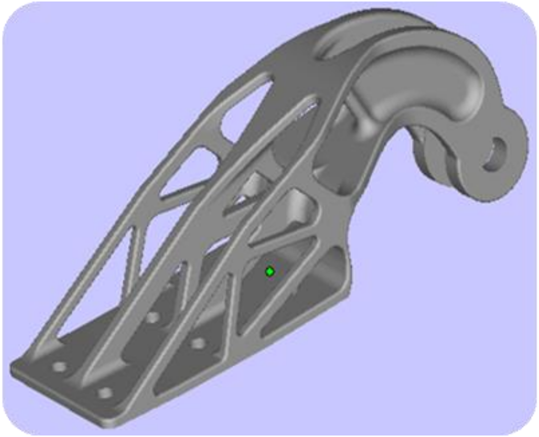
Topology Optimisation



(courtesy of GE)

Selective Laser Melting - Topology

Structural efficiency can be improved by enabling optimised topology that could not normally be achieved by machining or casting.

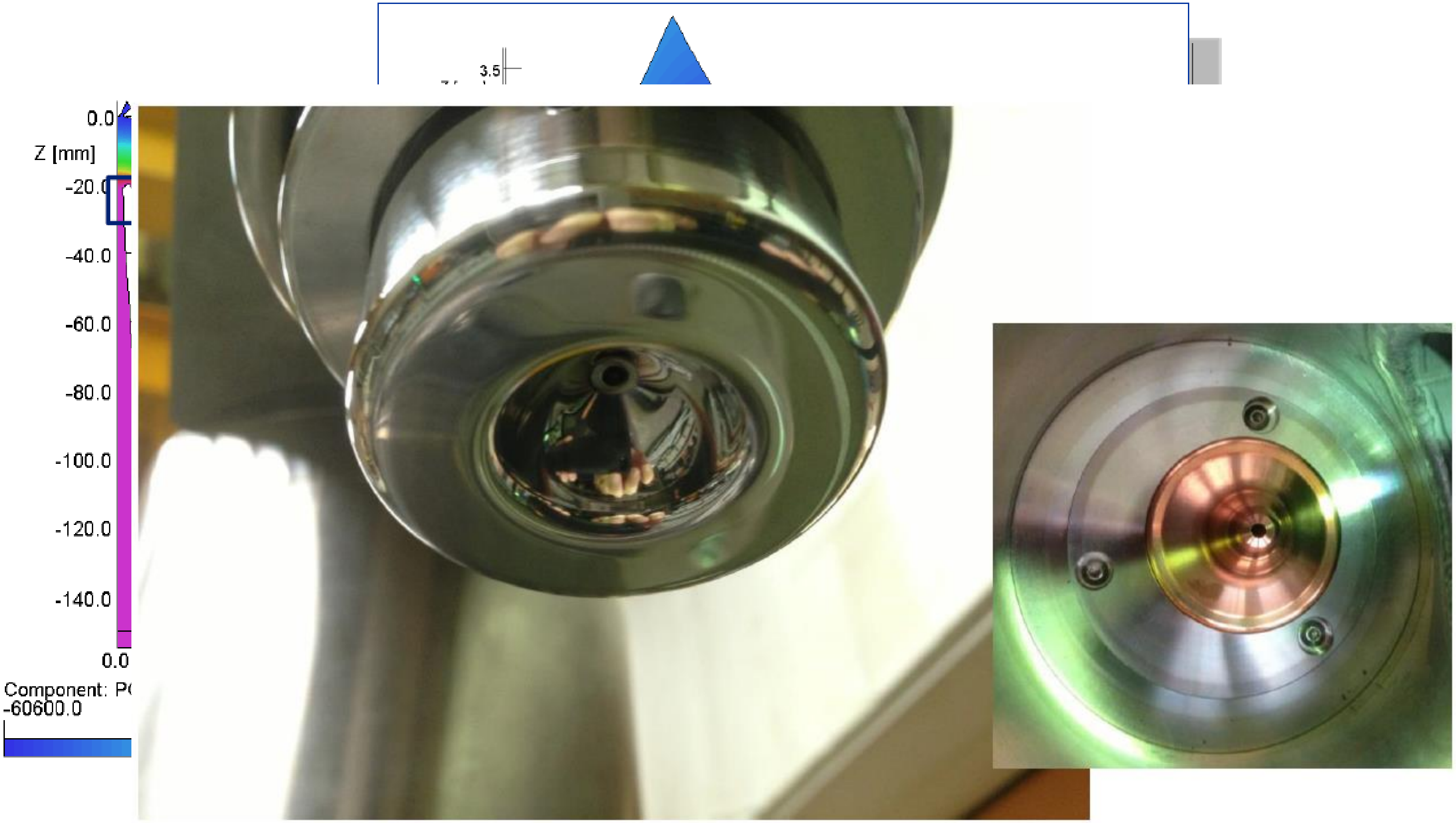




A collaboration between the following organisations: TWI Ltd, University of Exeter, EADS UK, Bombardier Aerospace plc, TISICS Ltd and Materialise UK. The Project was managed by TWI Ltd and partly funded by the TSB under the Technology Programme ref: "AB183A". TP No: TP11/HVM/6/I/AB183A

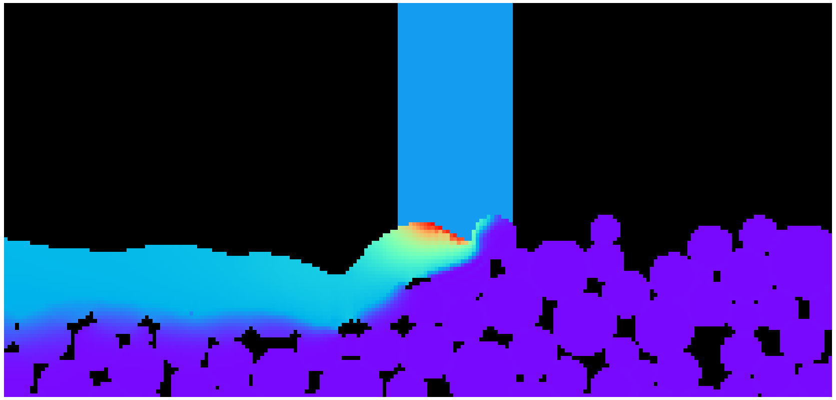
Added Value by Laser Assisted Additive Manufacture

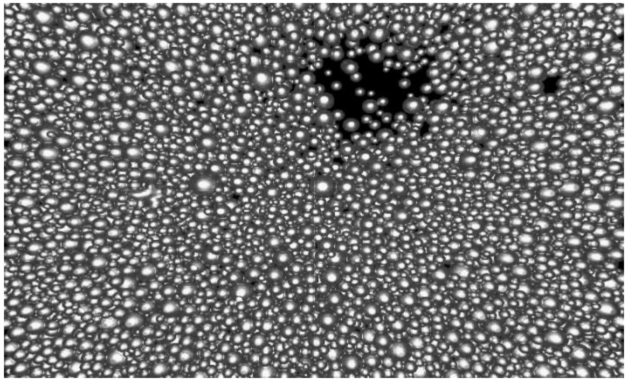
Images Courtesy of AVLAM

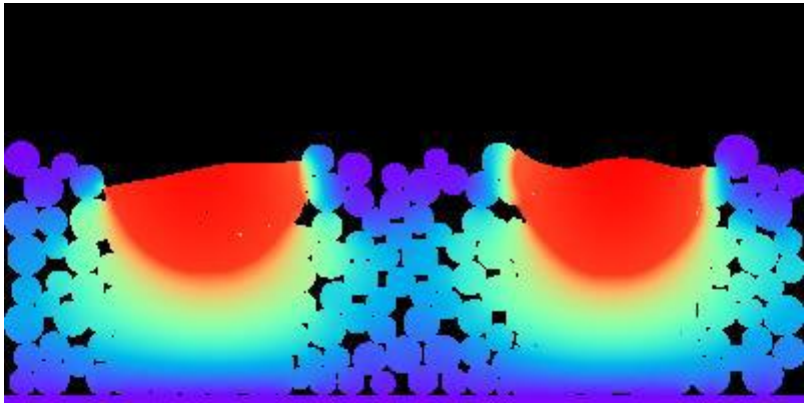
Equipment Capability - FastEBM

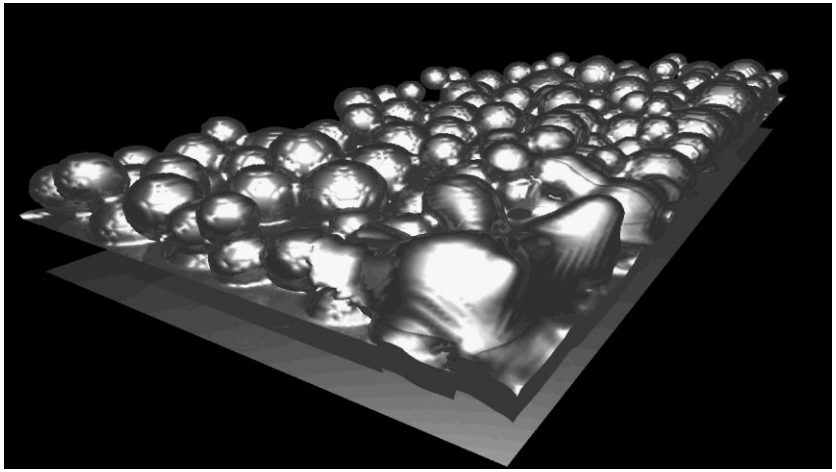


Process Modelling - FastEBM

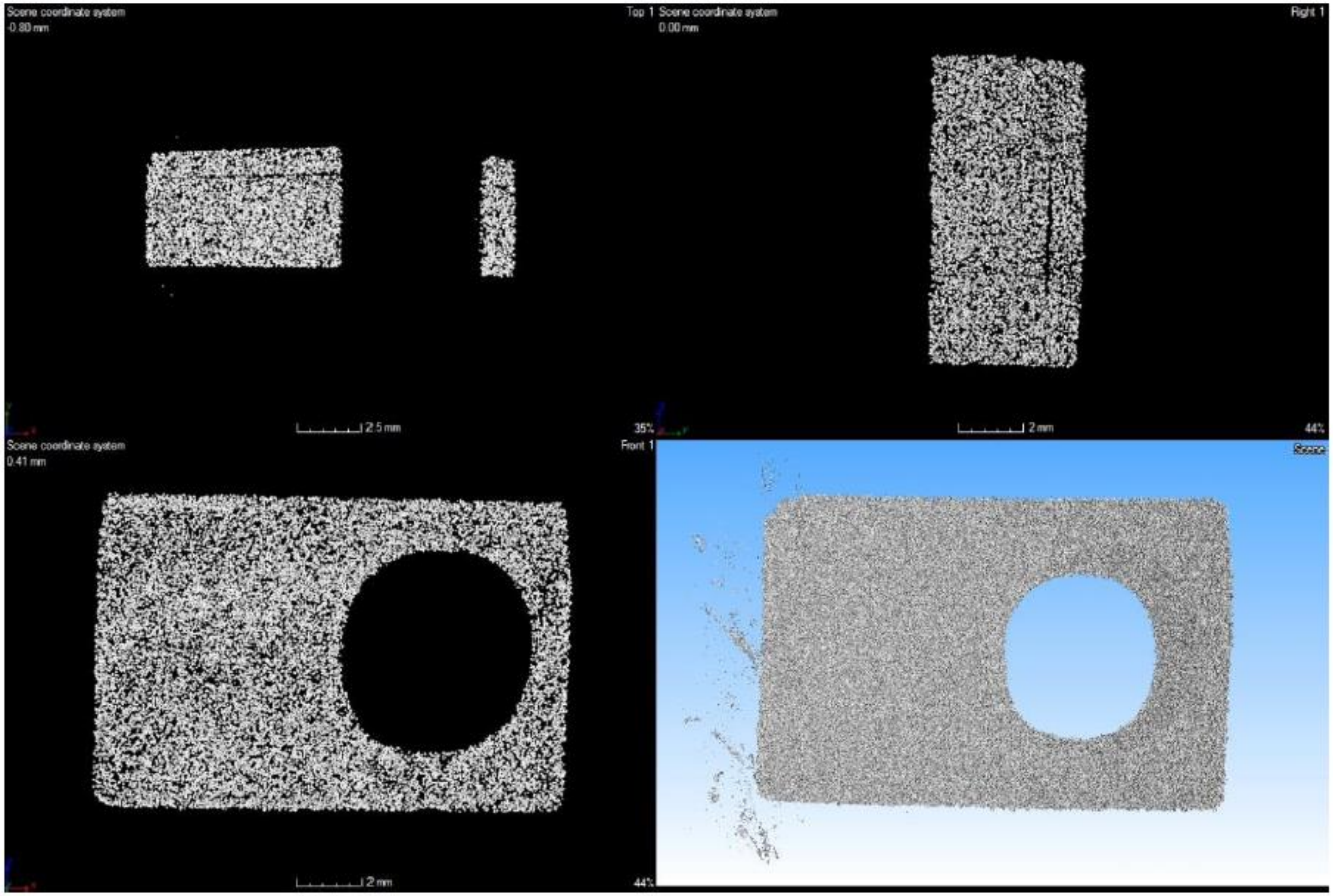








NDT - CT Scanning



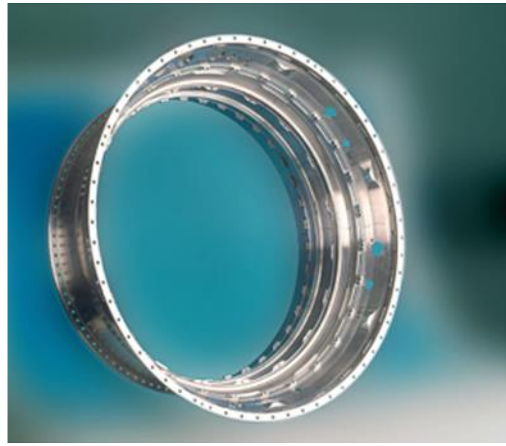
Material and Cost Reduction

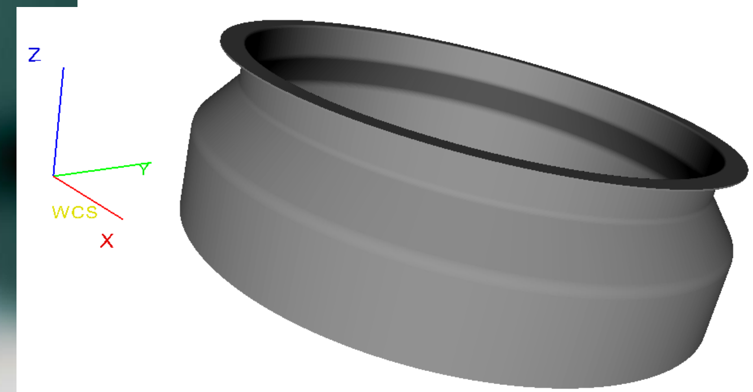
EC Projects MERLIN

Aims
- Deposition procedures for combustion chamber parts.
- Material IN718.
- Reduce time to manufacture (2-3 months -> 6 hours).

Challenges
- Complex shape – overhanging features and fillet radii.
- Thin wall (0.8mm) and Ra (15-25 microns).
- Large aspect ratios

i.e. thin wall (0.8mm) vs. overall build height (~100mm)





300mm diameter

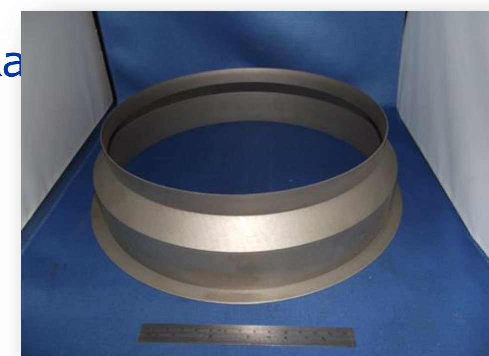


Image Courtesy of TWI

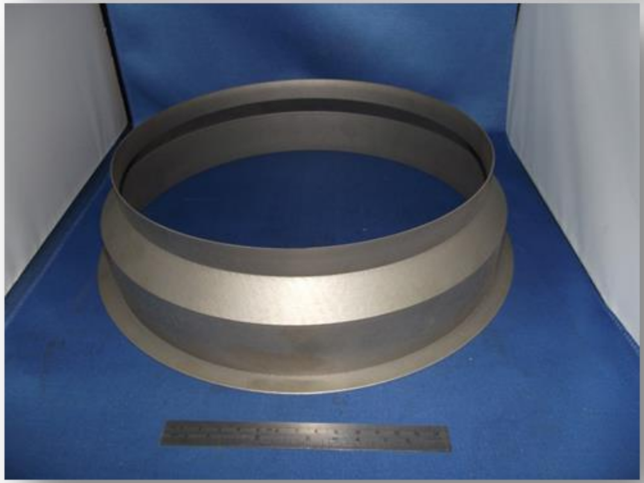
Lead Time Reduction

Cost effective manufacturing of existing parts/designs

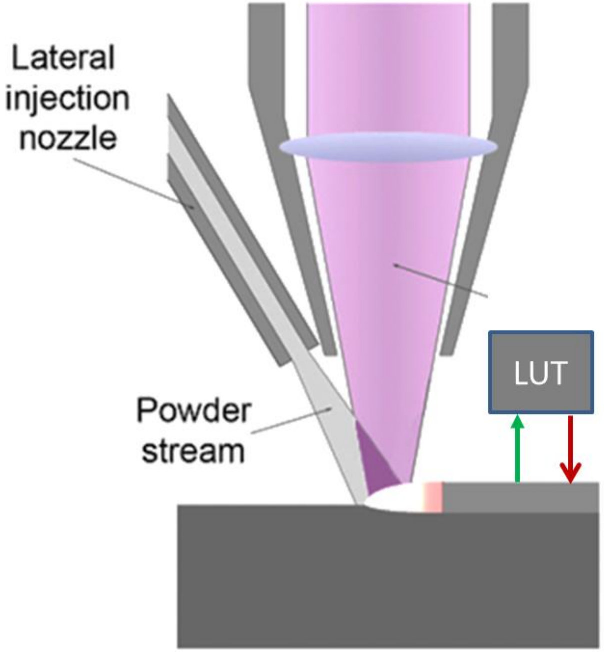
- Reduction of raw materials cost
- Replacement of milling/casting

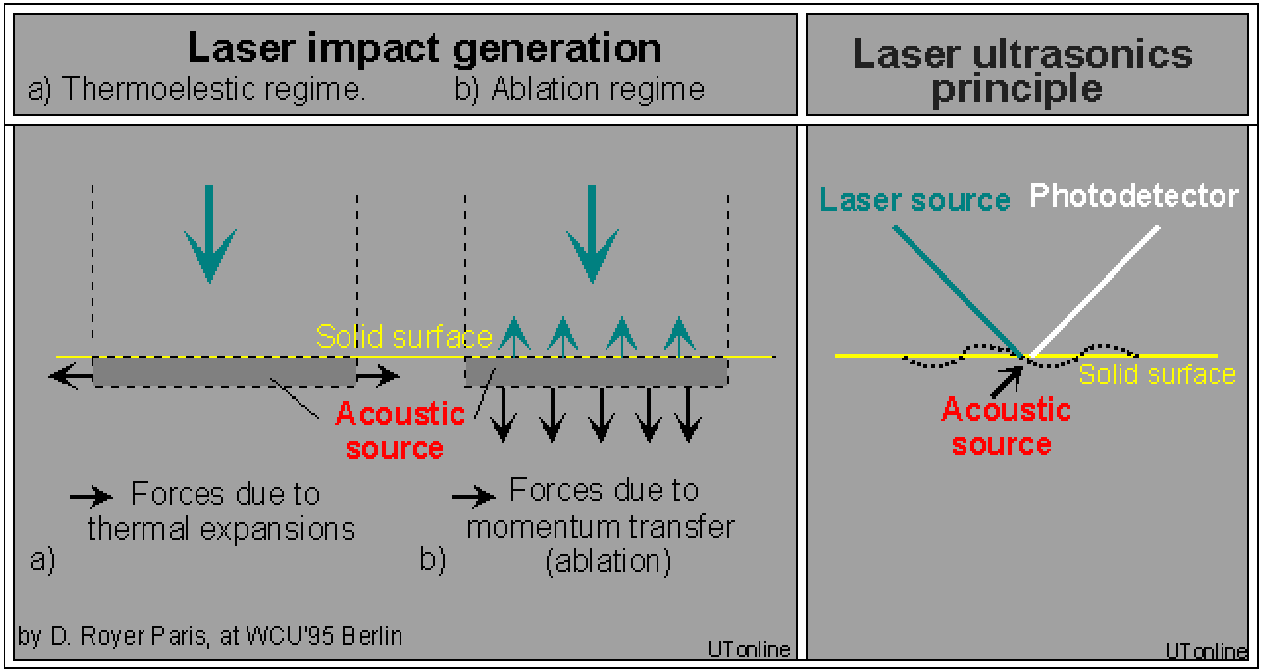
R&D steps for realisation

- Part quality
- Material characterisation/validation
- Process qualification

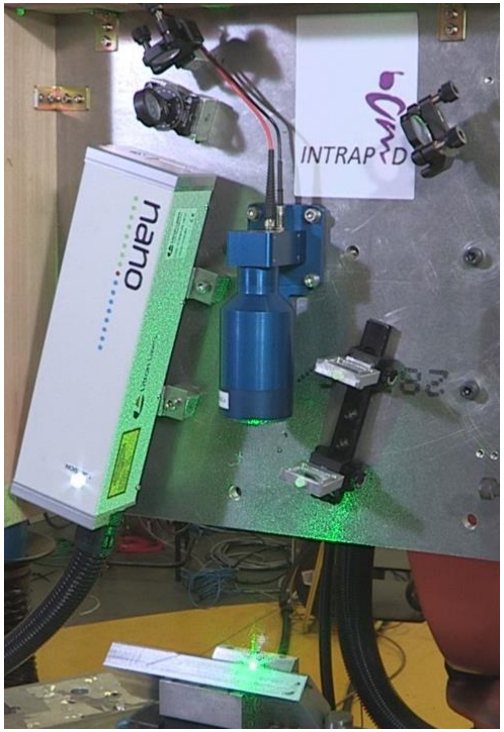


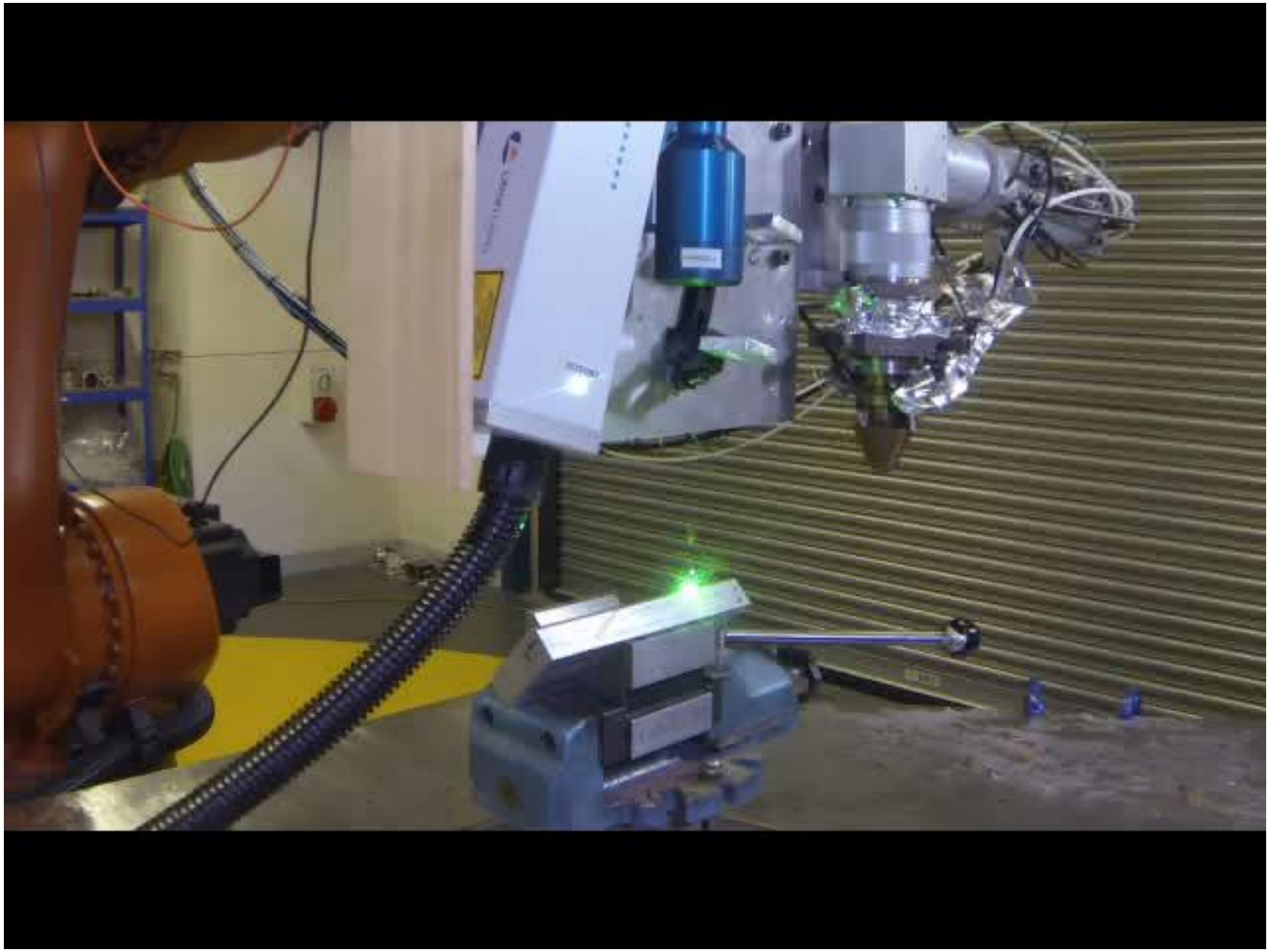
Inline LUT NDT Inspection





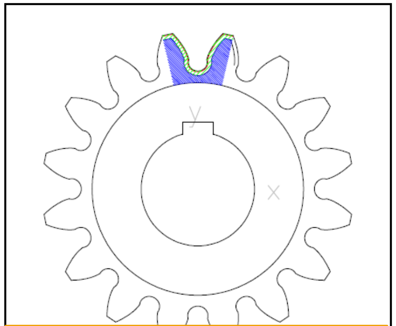
Laser Ultrasonic Testing





EC Projects: AMCOR

- Automotive FGM gears
- Cladding of large hydraulic cylinder piston rods – to replace PTA process
- Repair of broach machine tools
- Cladding of valves used to introduce steam into power station turbines
- Hybrid manufacture of cutting rollers used for cutting rocks

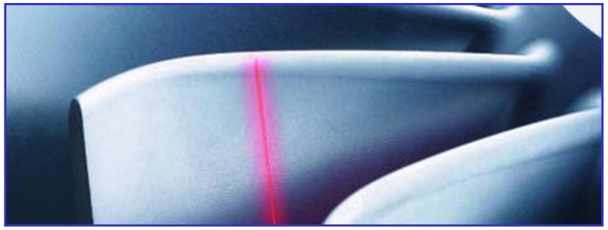


FGM Automotive gear

Failed HVOF coating

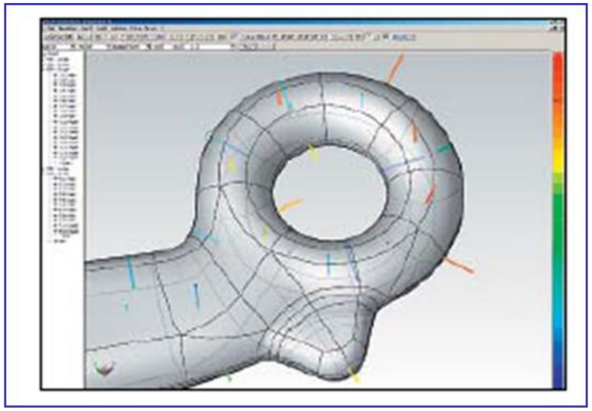
Failed PTA coating

Rock cutting roller after use



Integrated geometric scanning for repair and inspection

Images Courtesy of SKM and BCT

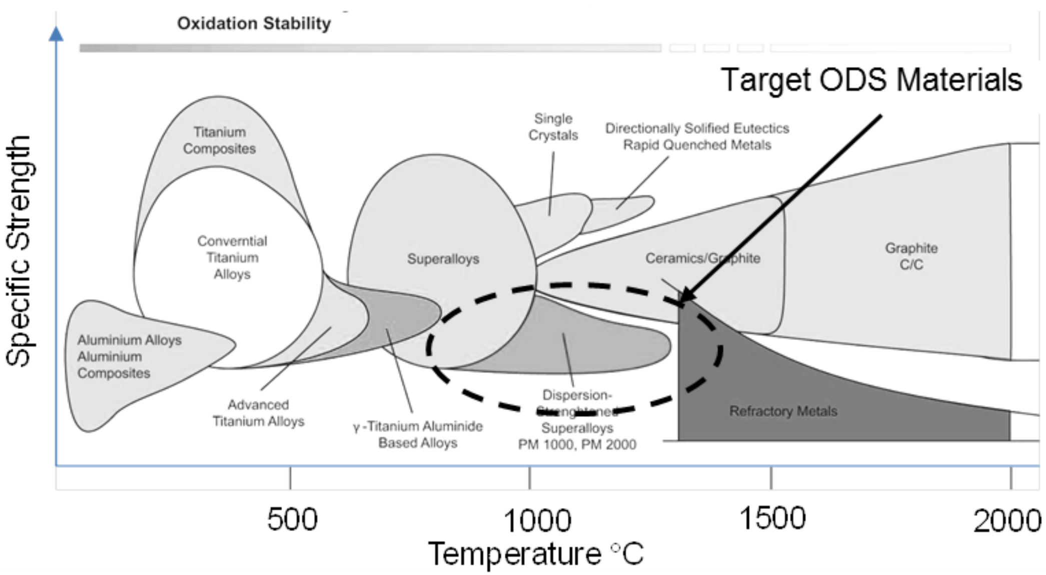


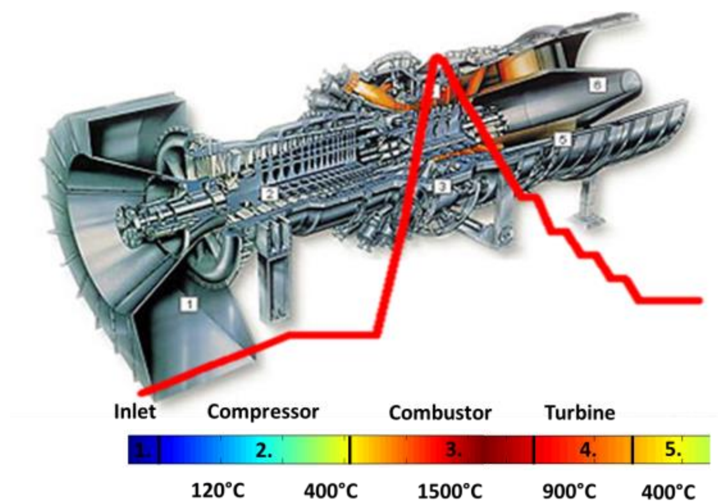
Multi-axis non-planar tool path generation

Images Courtesy of AMCOR

OXIGEN Project

- Oxide Dispersion Strengthened (ODS) alloys for high temperature power generation component manufacture.
- Development and manufacture of specialist powder alloys (Mechanical Alloying) and demonstrator manufacture using laser AM technologies.
- Prospect of higher efficiency power generation turbine systems.





ManSYS
3Dprintingplatform.com

MANufacturing decision and supply chain management **SYS**tem for additive manufacturing

www.mansys.info

TWI activities in AM

Understand the processing parameters of LMD and SLM and new materials.

Challenges being addressed

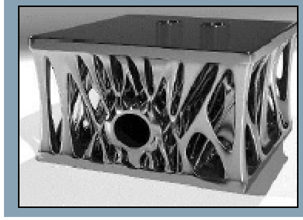
- **Process and Material Capability and Stability**
- **Productivity**
- **Design and Implementation**
- **Business models**

Re-engineering/Design for AM

Involved in the development of AM standards through ASTM

Strategy Case Study: MTU (Aero)

Phase 3: New AM Design



Manufacturing of functional structures
to reduce weight and cost (bionic design)

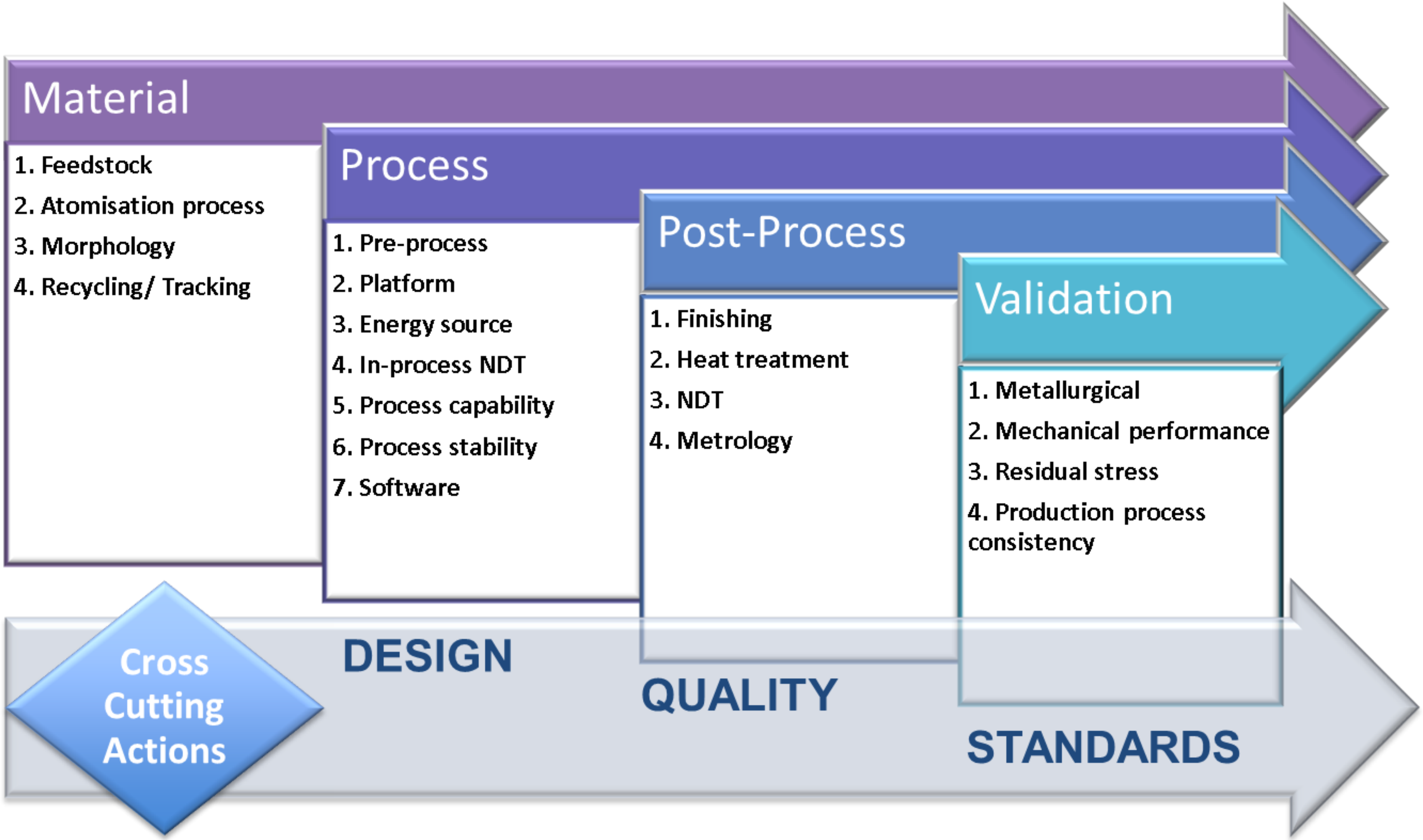
Phase 2: Substitution

Cost effective manufacturing of raw parts
Substitution of castings

Phase 1: Tooling, Rig and Development

Manufacturing of tooling,
Rig- and development hardware

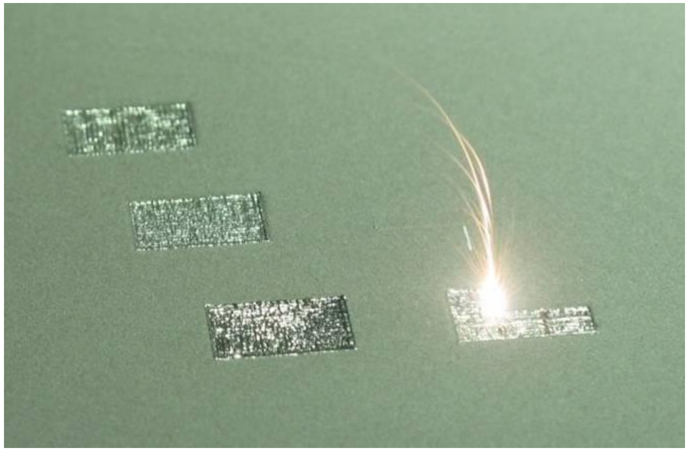
Needs: Process Chain Development



TWI Laser Additive Manufacturing

1 – Nozzle powder delivery (Laser Metal Deposition)

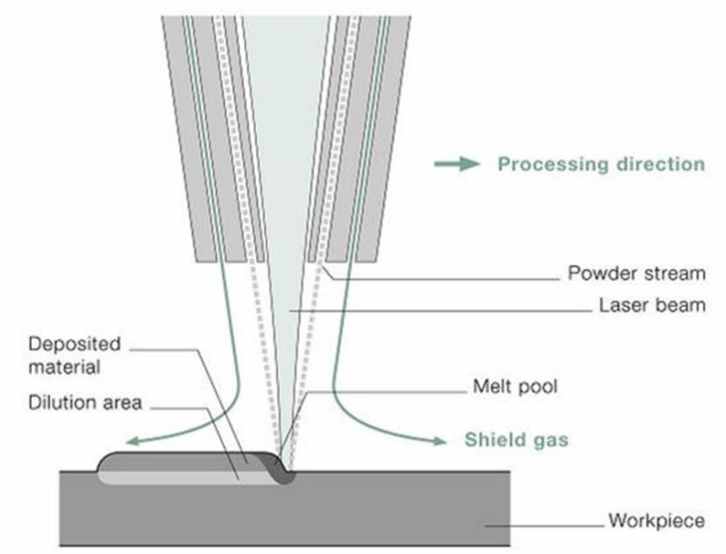
2- Powder bed deposition (Selective Laser Melting)



Technology Comparison

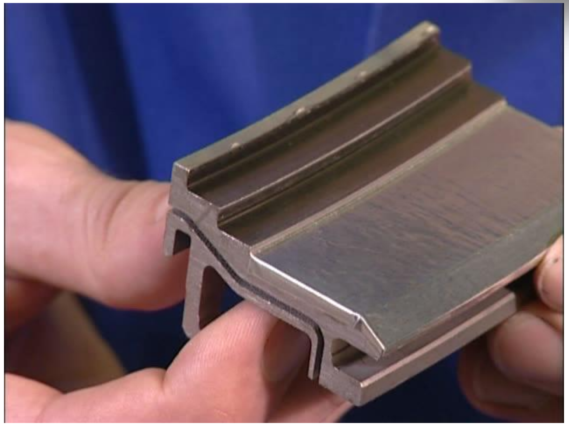
Characteristics	LMD	SLM
Materials (procedures development)	Large Materials Diversity (Ni, Ti, Al, CoCr alloys….)	Large Materials Diversity
Multi-Material Capability	Yes (metal matrix, FGM)	No
Part Dimensions	Limited by manipulation system (e.g. 1000x500x2000mm)	Limited by the process chamber (e.g. 600x400x400mm).
Part Complexity	Self supporting (Limited)	Nearly Unlimited
Dimensional Accuracy	>200 µm	>100µm
Roughness (Ra)	40 -100µm	>5µm
Substrates	OEM part (conformal) surfaces	Flat build plate
Layer Thickness	200µm – 3mm	>20µm – 200µm
Powder Particle size	45 - 100µm	15-45µm
Applications	3D parts, surface cladding, OEM repair	Complex 3D parts

TWI LMD Hardware Overview



- TRUMPF DMD505 system (LMD 1)

  - 2m x 1.1m x 0.75m build chamber allows large and complex parts to be processed.
  - 1.8kW HQ (High Quality) CO_2 laser.
  - 0.25mm (minimum) spot size at focus position.
  - Variable laser spot size capability.
  - 5-axis beam manipulation for maximum flexibility.
  - 2-axis fully integrated rotary/tilt manipulator allows high tolerance cladding of cylindrical components.
  - Sulzer Metco Twin-10-C double hopper powder feeder (FGM LMD)



TWI

Robotic LMD Capability - Manipulation

KUKA KR30 (HA) Robot Cell

- 30kg payload, ± 0,05mm repeatability
- Radial reach of 2033mm
- High accuracy (HA) robot model for best ‘path following’ accuracy
- Sulzer Metco Twin-10-C single hopper powder feeder delivers consistent powder flow

New TRUMPF Disk Laser

Feeds both robotic LMD cells

REIS RV60-40 Robot Cell

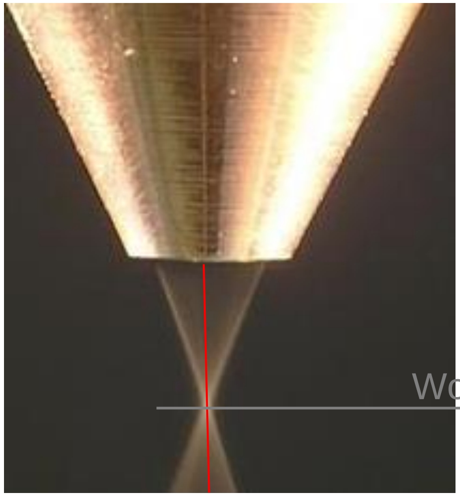
- 40kg payload, ± 0,1mm repeatability
- Radial reach of 2500mm
- Integrated rotary/tilt manipulator (8-axis in total)
- 2.5m long cylindrical components can be cladded
- Sulzer Metco Twin-10-C double hopper powder feeder (FGM LMD)

LMD Nozzle Technology

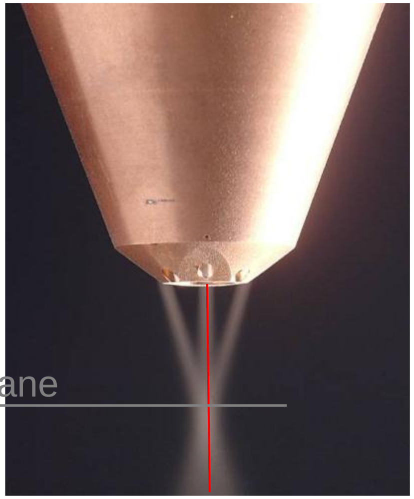
The Business end :-

Geometric Complexity

Coaxial

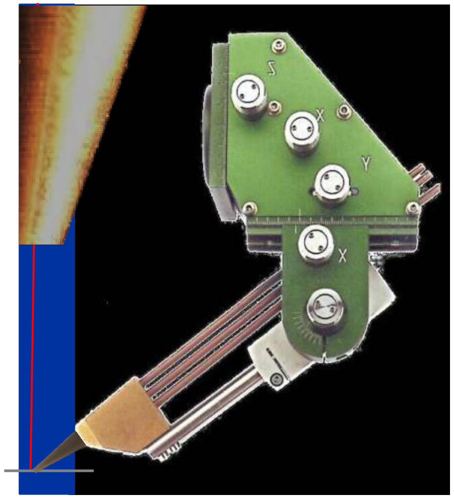


Multi-Jet



Working Plane

Off-Axis



Coaxial:

- Powder Spot ≥ 0.3 mm
- Laser Power ≤ 2KW
- Oxygen Contamination ≤ 20ppm

Multi-Jet:

- Powder Spot ≥ 1,5 mm
- Laser Power ≤ 6KW
- Oxygen Contamination ≤ 50 ppm

Off-Axis:

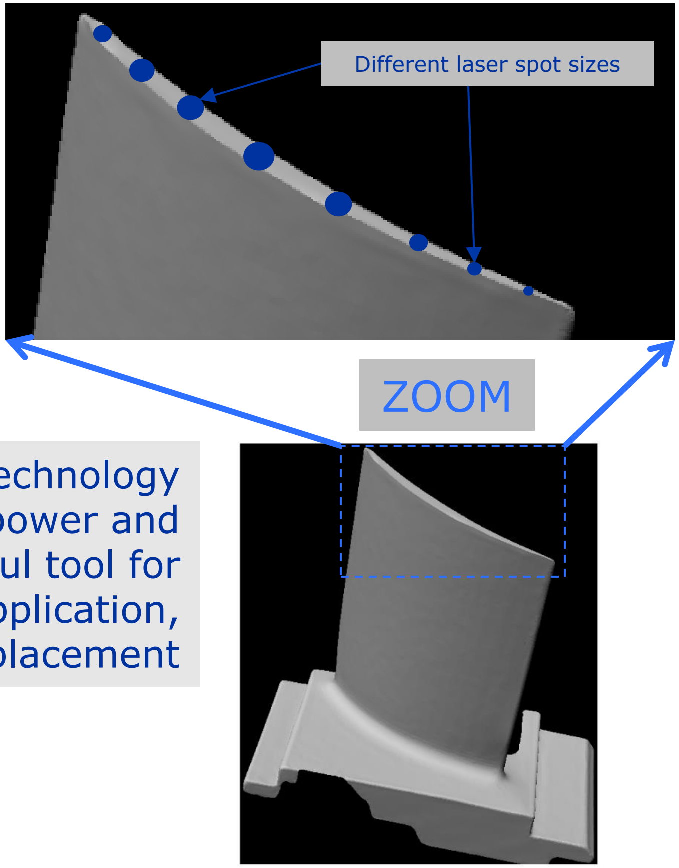
- Geometries with limited access
- Surface cladding

Deposition rate

Images Courtesy of Fraunhofer ILT

Robotic LMD Capability – Laser System

- Adjustable spot size technology
- Combine with variable power and speed to create a powerful tool for any aerofoil type application, especially 'full chord' replacement



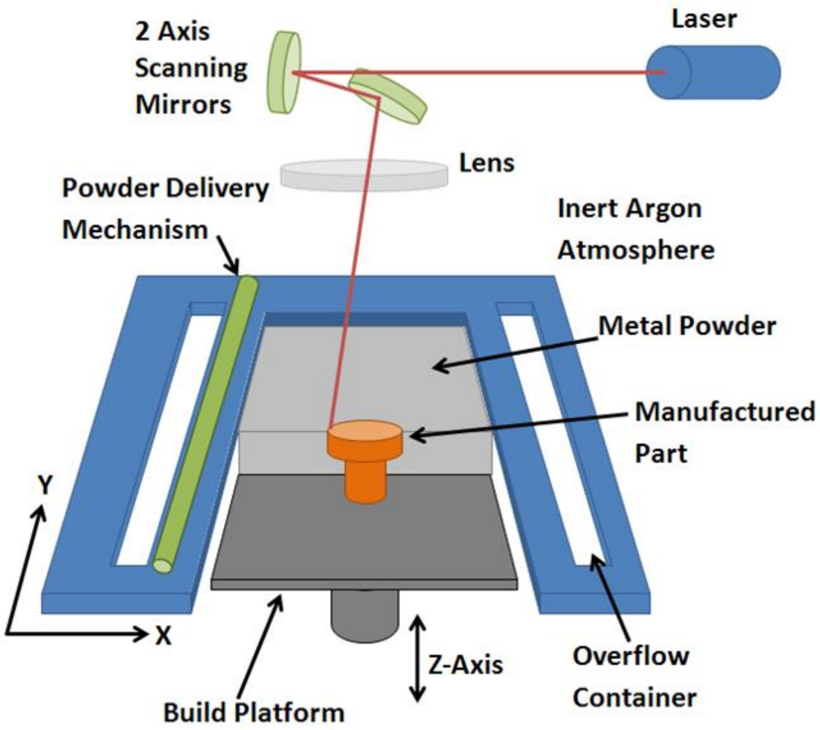
Typical aerofoil re-build

Powder Bed Processing - SLM

Ability to manufacture parts of virtually any complexity of geometry entirely without the need for tooling.

Process parameters:

1. Layer thickness
2. Exposure time
3. Point distance
4. Laser power
5. Focus position
6. Scan strategy
7. Boundary conditions
8. Hatch conditions



Process criteria:

1. Density
2. Surface finish
3. Mechanical properties
4. Dimensional accuracy

Image Courtesy of TWI

Selective Laser Melting Capability

Realizer SLM100	Renishaw AM250	Rapid Part System 1kW
		

Realizer SLM100

- Build volume:125(dia.) * 180(z) mm
- 200W fibre laser
- 20-50µm layer height
- Cp Ti, Titanium 6-4, Nickel alloys, CoCr and SS , Al

Renishaw AM250

- Build volume:250* 250 *280(z) mm
- 200W fibre laser
- 50-75µm layer height
- Titanium 6-4, Nickel alloys, CoCr, AlSi10Mg and SS

Rapid Part System 1kW

- Build volume:250* 250 *280(z) mm
- 1000W fibre laser
- 75-200µm layer height
- Titanium 6-4, Nickel alloys, Al alloys and SS

Images Courtesy of TWI

Design Optimisation for Additive Manufacture

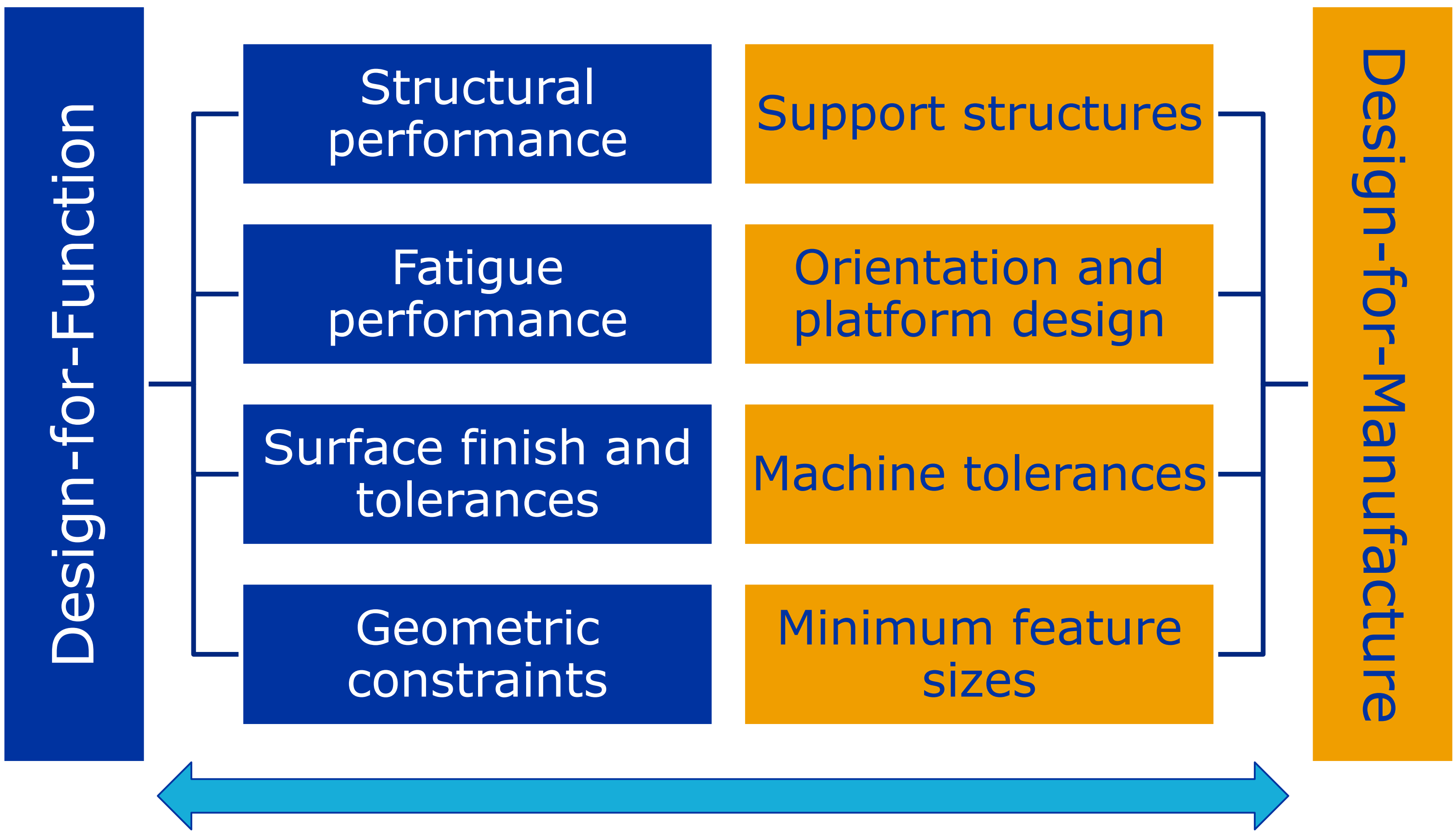
Used to create designs that *exploit* AM processes

Introduce complex geometries

(sub-structures and lattices)

Multiple-part assemblies combined into single builds

Design Optimisation at TWI for Additive Manufacture

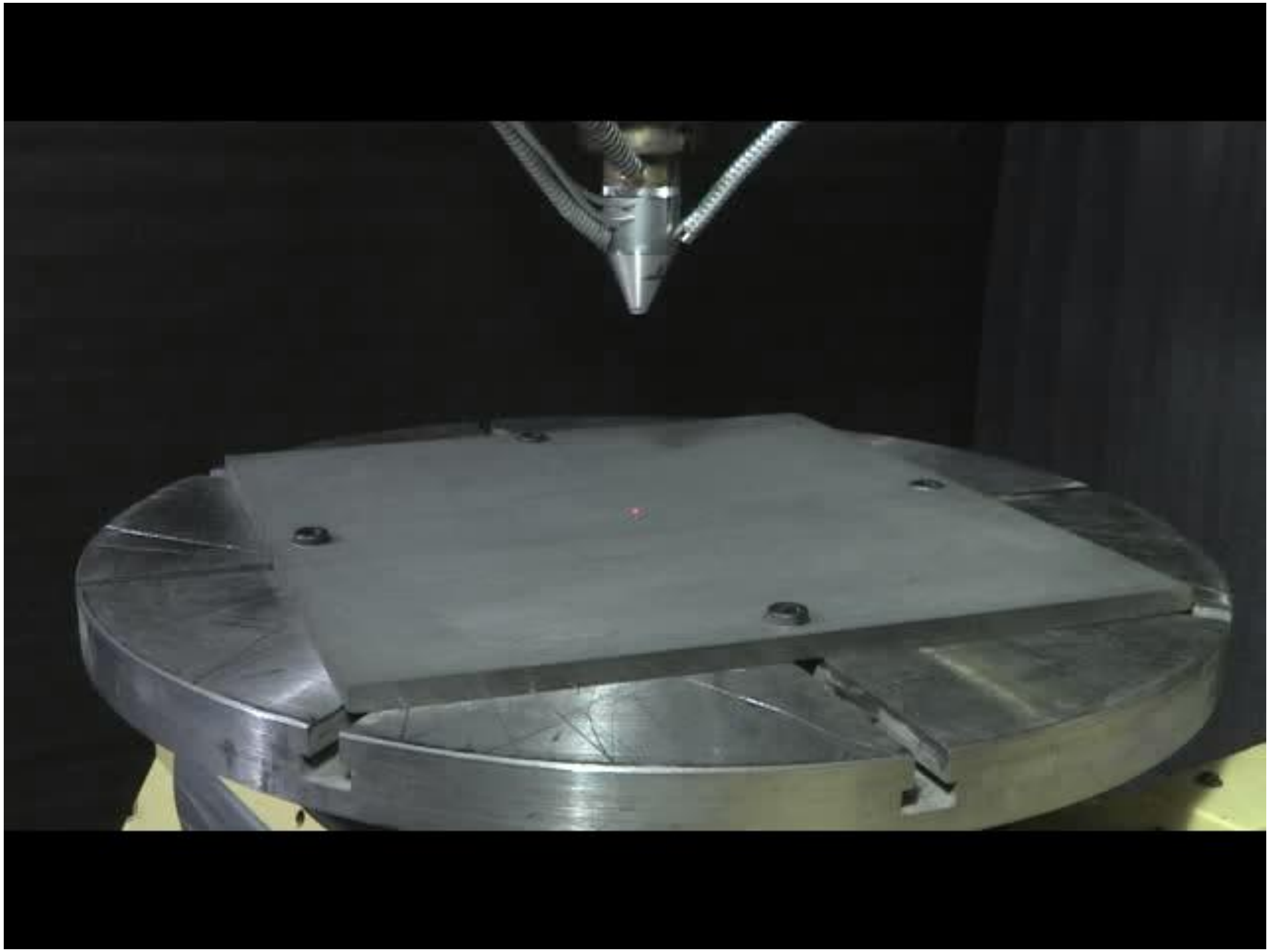


AlSi10Mg Mechanical properties

Sample Id	0.2% PS (MPa)	UTS (MPa)	4D Elong. (%)	5D Elong. (%)
104 AlSi10Mg Set 001 Pt1	238	429	6.8	6.4
104 AlSi10Mg Set 001 Pt2	237	435	7.2	6.9
104 AlSi10Mg Set 001 Pt3	238	435	4.9	4.8
104 AlSi10Mg Set 001 Pt4	244	444	5.2	5.1
104 AlSi10Mg Set 001 Pt5	252	447	3.9 +	4.1 *
104 AlSi10Mg Set 001 Pt6	252	432	4.6 *	4.4 *
104 AlSi10Mg Set 001 Pt7	253	424	4.6	4.2
104 AlSi10Mg Set 001 Pt8	247	355	2.9	2.7
104 AlSi10Mg Set 001 Pt9	245	376	3.5	3.3
104 AlSi10Mg Set 001 Pt10	250	411	4.3*	3.6

Improved UTS and comparable Elongation

Lead Time Reduction



Art!

Summary

1. 226Mn Euro EC funding, 335Mn Euro Budget
2. 12 FP6, 60 FP7 Projects 88 in total
3. Strategic Research Agenda
4. Drivers, Focus areas, Risk, Timescales…
5. Targeted Development Examples
6. TWI Capabilities
7. LMD and SLM
8. Holistic approach – Materials, Pre, Process, NDT, Post, Validate

Thank You

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