



WAAMMat Programme Overview

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www.cranfield.ac.uk



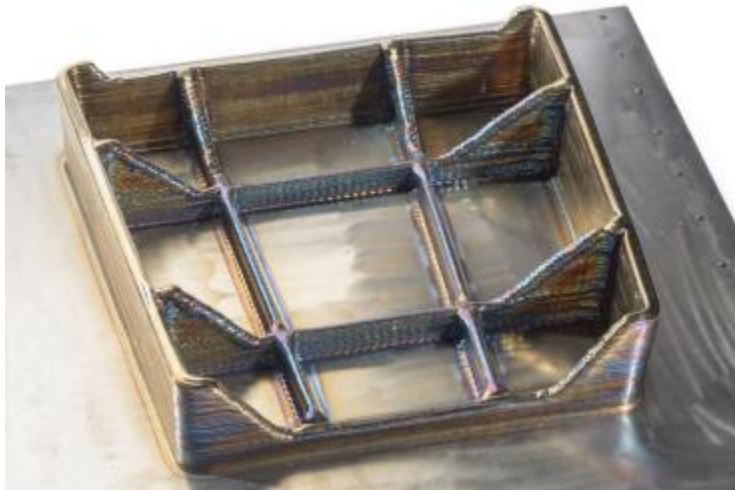
WAAM business drivers

- Cost savings compared to current manufacturing processes
- Lead time reduction compared to forgings
- Performance enhancement through
 - Replacement of e.g. castings by higher performance materials
 - Weight savings by topological optimisation
 - New materials
 - Mixed material systems



WAAM business driver – cost saving case studies - Bombardier rib

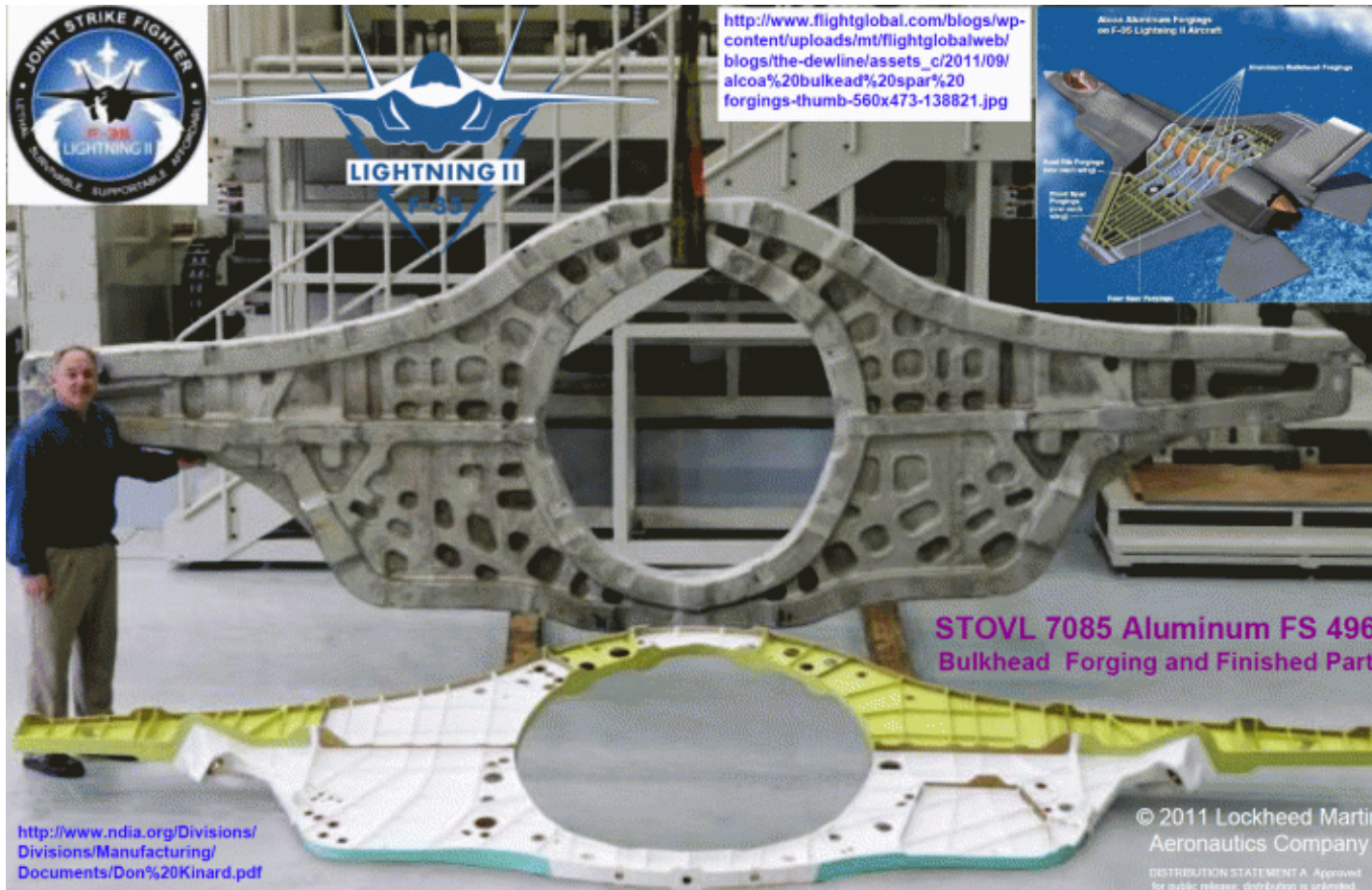
Design option	Mass (kg)	BTF	Cost (£k)	Cost red.
Original machined	20	12	16.2	-
WAAM + machining	20	2.3	5	69%



Design option	Mass (kg)	BTF	Cost (£k)	Cost red.
Original, machined	36	12	1.6	-
3 WAAM + machining	36	2.3	0.7	55%



WAAM systems - where we are aiming - HELP!



Aluminium:

- 14 months for forging
- 4 months for machining
- 90% waste

Titanium:

- 10 times worse problems

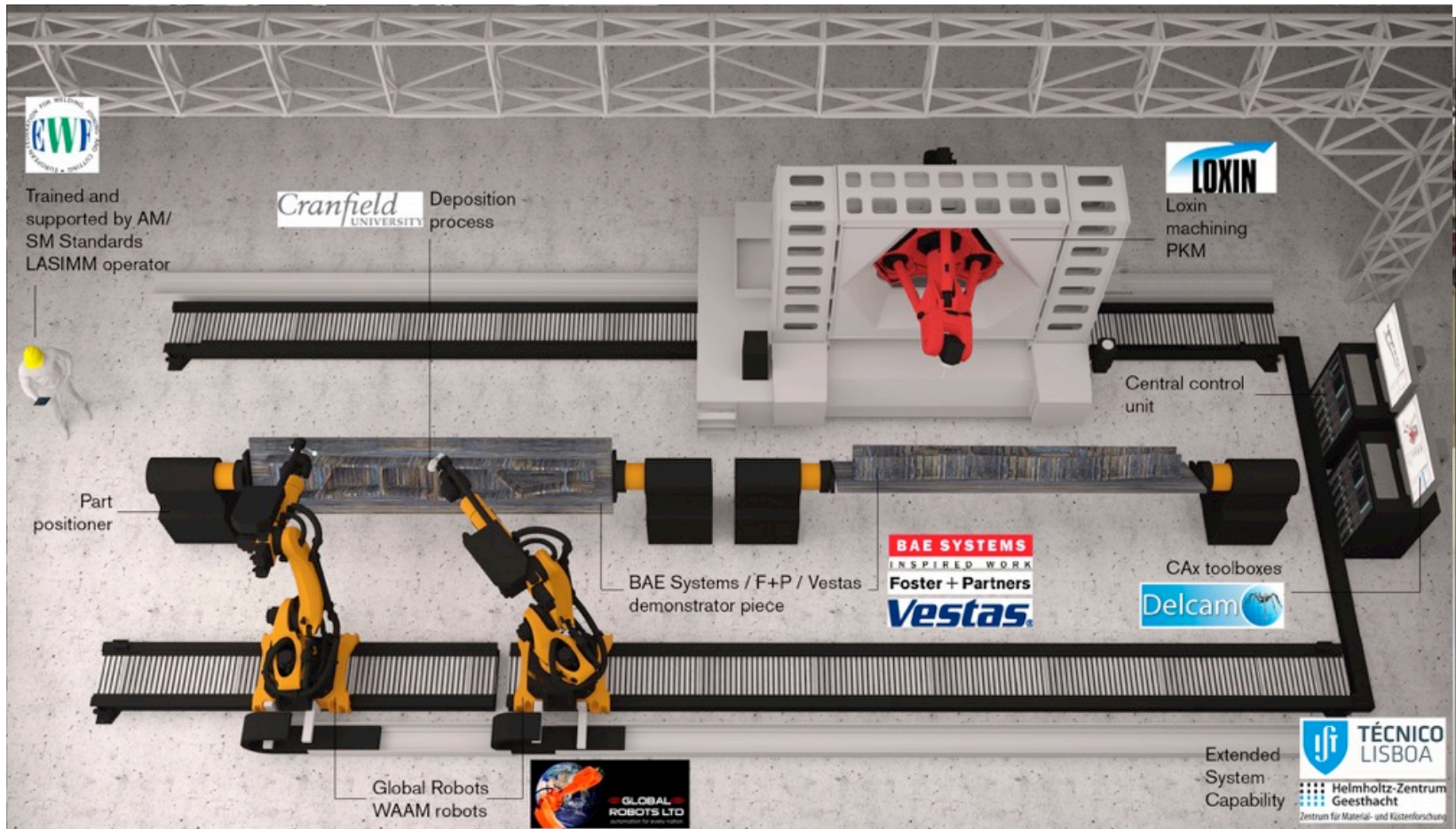


Worlds largest 3D printed (metal) part – 6 m long 300 kg aerospace grade aluminium spar





WAAM system developments – multi robot systems for parallel processing





WAAM – major technical challenges and activities

- **System development - CAD drawing to part**
 - **Software and full automation**
 - WAAMDesign
 - **WAAMSoft**
 - **WAMMCtrl**
 - WAAMAPIs
 - **Hardware**
 - **Process monitoring**
 - Fault detection
 - Component cooling
- **New materials and combinations**
 - **High strength aluminium alloys**
 - Superalloys
 - Refractory metals
 - Maraging steels
- **In process NDT**
- **Qualification – Q3**



WAAMMat – Technical Programme Overview

WAAMMat Technical Programme

System Development

Processes

- WAAM variants
- Process algorithms
- Build strategies
- Higher build rates
- Increased fidelity
- Wall width control
- Compensation strategies
- WLAM and WLAAM

Other processes

- 2.5D rolling
- Alternate cold work methods
- Grain structure measurement
- Hybrid manufacture
- Integrated NDT
- Defect repair

Hardware

- Soft plasma
- Precision wire feeding
- Local shielding
- Ruggedisation
- Process monitoring
- Control systems
- Robotic systems
- Machine tools
- Large structures
- Multi processes

CAM Software

- Toolpath planning
- Intelligent partitioning
- Build strategy allocation
- Interface management
- Layer height control
- Build sequence GUI
- Auto build strategy
- Control

Commercial systems

Mature WAAM

Materials

New

- High strength aluminium
- Refractory metals
- Maraging steels
- Superalloys
- Metal foams
- MMCs
- Low CTE materials
- Mixed material systems

Performance

- Tensile
- Fatigue
- Fracture toughness
- Crack propagation
- Corrosion
- Effect of defects

Qualified materials

WAAM Industrial Applications

Design Tools

Optimisation

- CAD to CAM
- Hybrid manufacture tool
- Knowledge expert system
- Computer aided planning

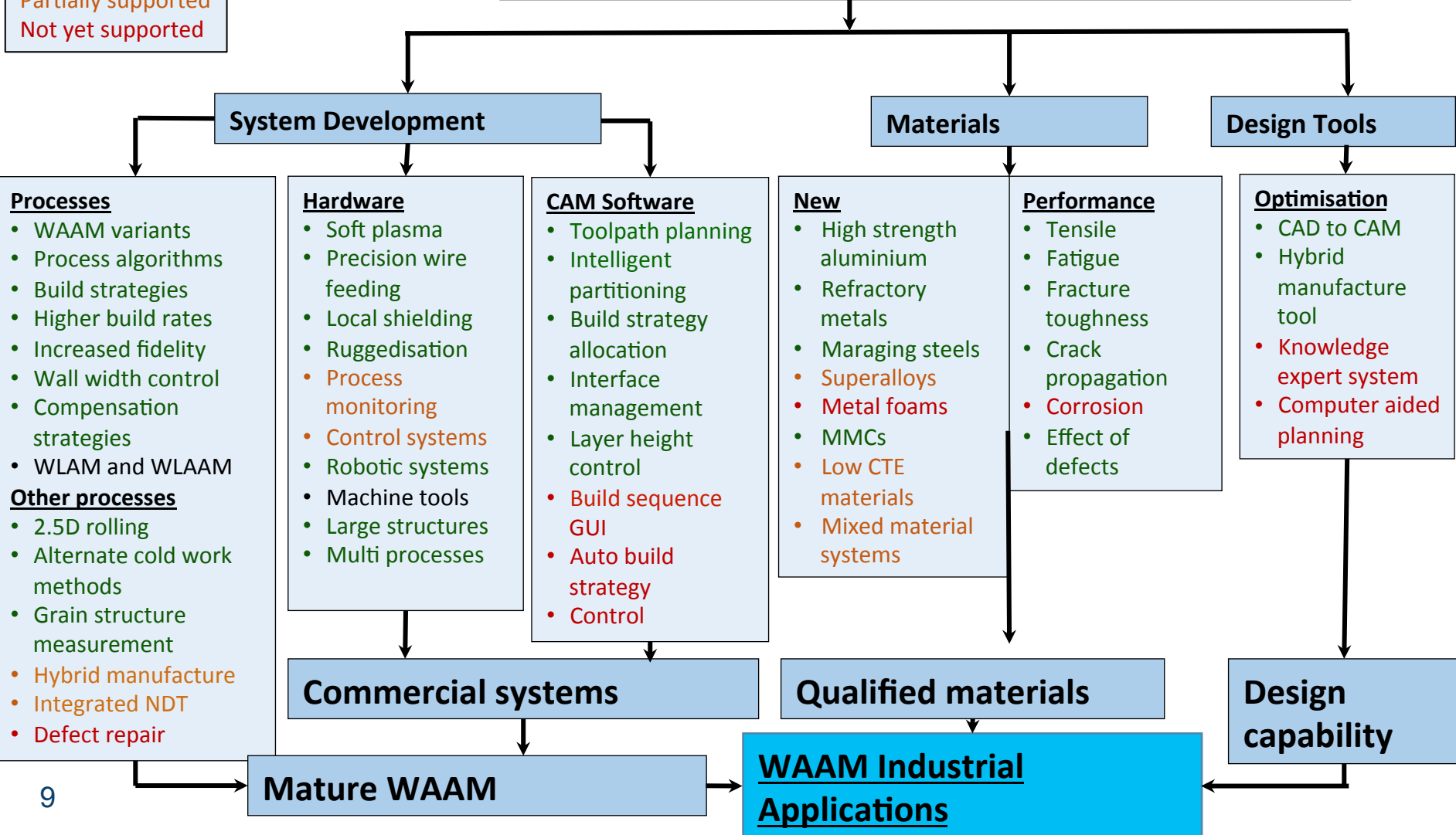
Design capability



WAAMMat – Technical Programme Overview

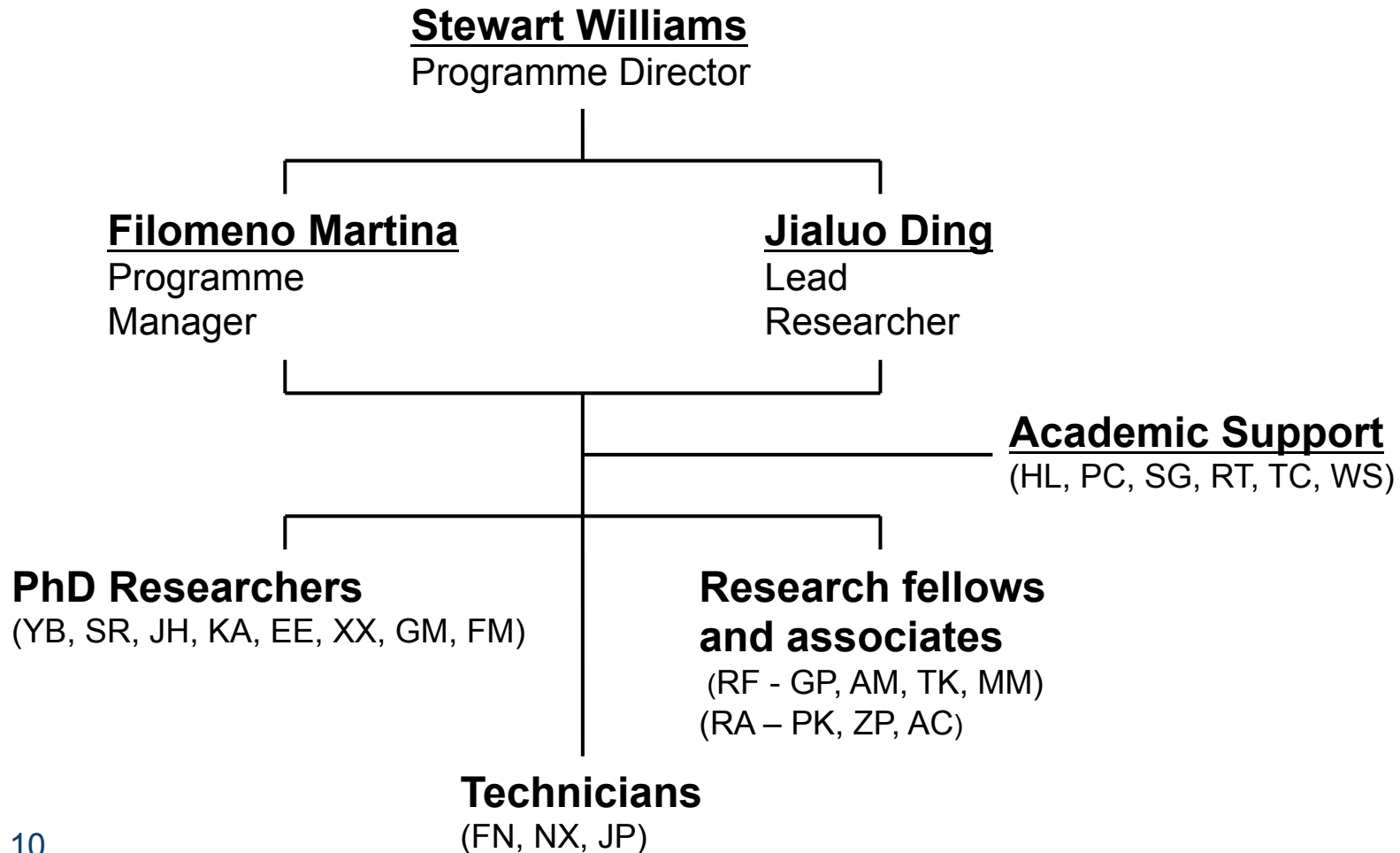
Fully supported
Partially supported
Not yet supported

WAAMMat Technical Programme





WAAMMat Research Programme Structure





WAAMMat Programme – Cranfield team

WAAMMat Programme Partner Overview

Academic Cranfield

Stewart Williams

Programme director

Jialuo Ding

Automation, software, part building

Filomeno Martina

Programme Manager

Paul Colegrove

Cold work, modelling,

Helen Lockett

Design and design tools

Supriyo Ganguly

Metallurgy and F&DT

Ralph Tatum, Tom Carrol

Optical instrumentation

Wojciech Suder

WLAM and WLAAM

James Widbourne

Control systems

Yifan Zhao

Signal Processing

Researchers Cranfield

Gonzalo Pardal

Cooling, local shielding, hybrid laser

Anthony McAndrew

Multi dimension rolling, part building, modelling

Pawel Kurzsniky

Control systems and software

Zsolt Pinter

Al deposition, part and component building

Armando Caballero

New materials

Thomas Kissinger

On-line sensing

Michelangelo Mortello

WLAM and WLAAM

Uzami

Part building

Currently 29 people on programme + 3 technicians

Students

11 x PhD students

- Kwasi Ayarkwa – novel Al structures
- Gianrocco Marinelli – refractory metals
- Jan Hönnige – alternative cold work
- Xiangfang Xu – mixed materials
- Florent Michel – Software for WAAM
- Eloise Eimer – Al development
- Philippe Bridgeman - manufacturing strategies
- Alex – Process monitoring and control
- Phillipe Taiye – Fatigue behaviour
- ✓ **2 x new PhD students starting Jan 2017**
- **Various MSc projects**



WAAMMat Programme - Academic Partners

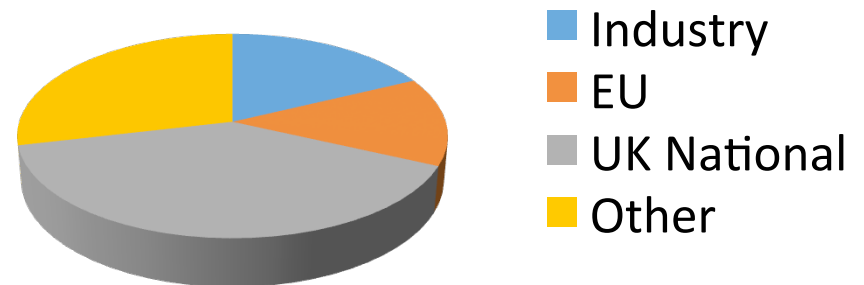
Institution	Lead investigator	Technical area	Resource
Manchester U	Phil Prangnell,	Materials Science and Modelling – Q3	1 x res, 1 x PhD
U of Nottingham	Steve Sharples	On-line grain size measurement	1 x res
IIT Bombay	Karunakaran	Integrated machining, peening	2 x PhD
Heriot Watt U	Andrew Moore	Flow visualisation, process monitoring	2 x PhD
NE University China	Yuchun Zhai	Aluminium wire development	
Open University	Sanjooram Paddea	Residual stress characterisation	1 X Res
Bath University	Stephen Newman	Process monitoring	1 x Res
Coventry University	Xiang Zhang	Fatigue and DT, effects of defects – Q3	1 x Res, 2 x PhD
Strathclyde University	Gareth Pierce	In-process NDT – Q3	1 xRes
Bristol University	Harry Coules	Fatigue and DT, effects of defects – Q3	1 x PhD
Surrey University		Aluminium wire quality – Q3	1 x PhD
Delft University	Ian Richardson	Thermal cycle simulations, microstructure – Q3	1 x PhD
IST	Luisa Quintino	NDT and design	2 x PhD

11 Academics + 18 researchers/students
> 60 people in total working on WAAM



WAAMMat Programme – features

- WAAMMat is a rolling technology programme incorporating a wide range of projects and activities
 - Industry sponsored research
 - Projects funded by outside bodies (e.g. EU, EPSRC, TSB)
 - PhDs
 - Masters projects
 - Internally funded projects
- Currently 70 projects – total value >£4.5M,





WAAMMat Programme – Industry partner types

Partner Type	Rights	Requirements
Full	<ul style="list-style-type: none"> Perpetual royalty free license to all foreground IP from the core programme whilst partners <u>Full access to detail of all research outputs in core projects</u> Access to background IP needed to exploit WAAM Member of industry advisory group 	<ul style="list-style-type: none"> Sponsorship of research projects with minimum requirement of £120k in a two year period Sponsored research must form part of the WAAMMat core programme
Associate	<ul style="list-style-type: none"> <u>Visibility</u> of all research outputs from the core projects Access to background IP needed to exploit WAAM Member of industry advisory group by invitation only 	<ul style="list-style-type: none"> Contribution to the WAAMMat by for example <ul style="list-style-type: none"> Non-core research project sponsorship Smaller research project contribution

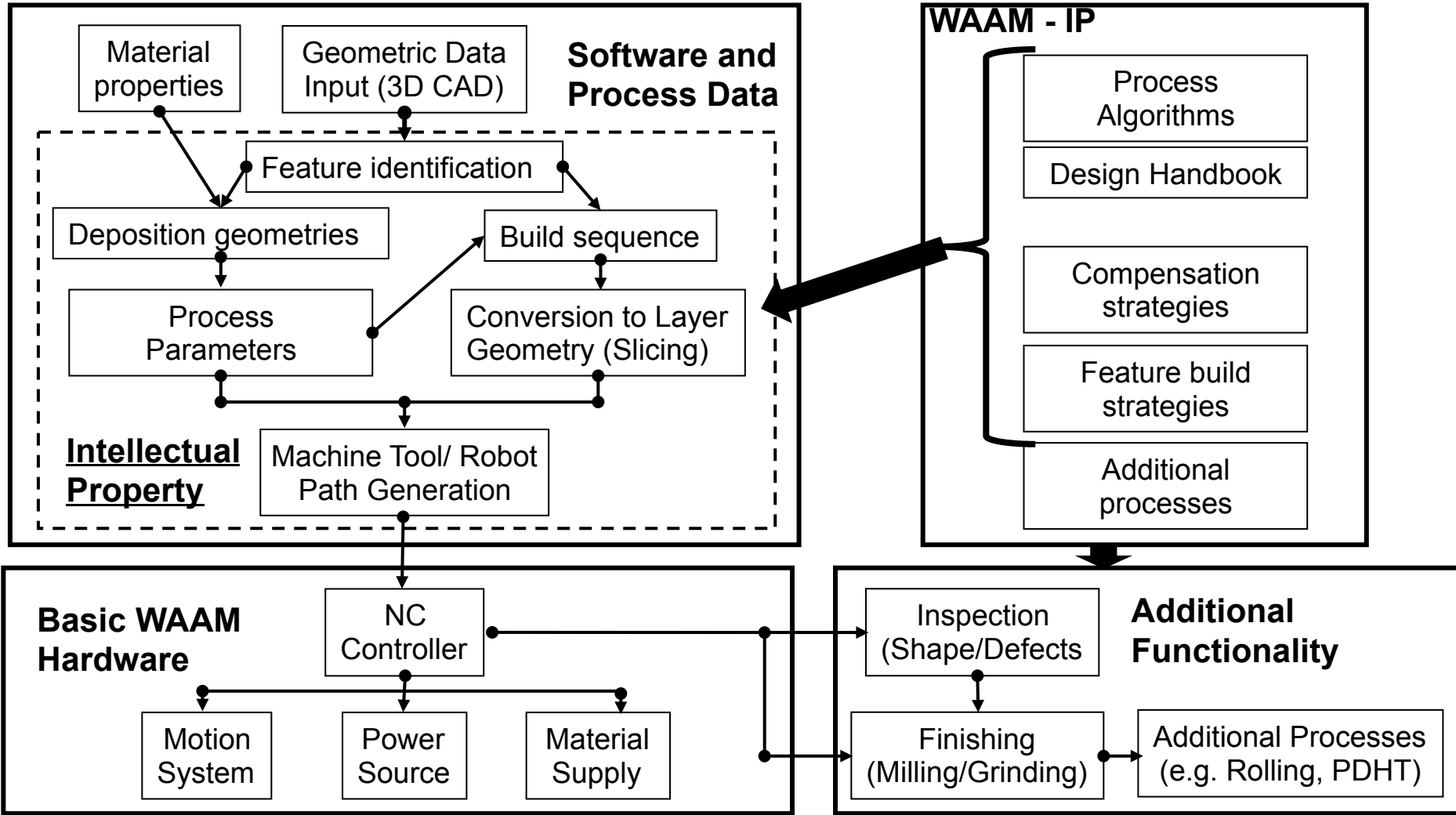


WAAMMat industry members

WAAMMat Full		Associate or collaborative	
<u>UK</u>	<u>International</u>	<u>UK</u>	<u>International</u>
BAE Systems	Lockheed Martin	CCFE	Volvo Trucks
Global robots	NEIMM	Delcam	Constellium
DSTL	UTRC	Airbus Group	Fanuc
Glen Almond	FMC	PWP	Air Products
	Linde Gases	AWE	EWM
	Otto Fuchs	Technical arc	Fronius
		Thales	Select Arc
		Weir	Bekaert
		Norman Foster & P	
<u>In discussion</u>			
3D systems	Roxel	Boeing	Northrop Gruman
Keppel	Air Liquid		



WAAM Basic System and IP





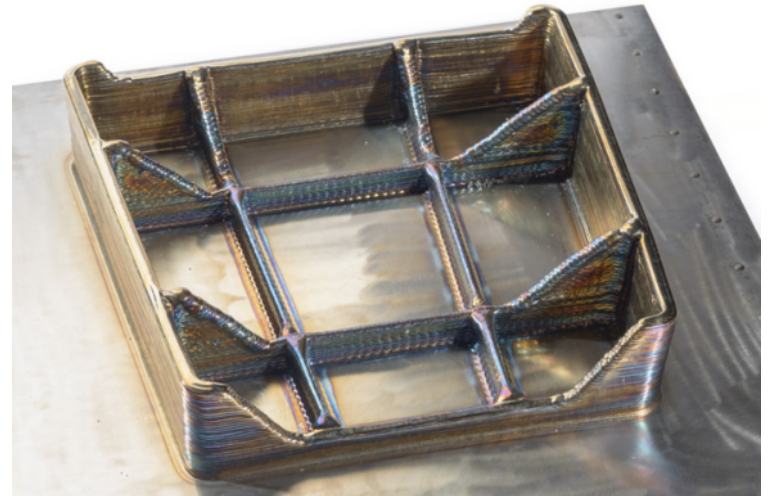
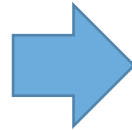
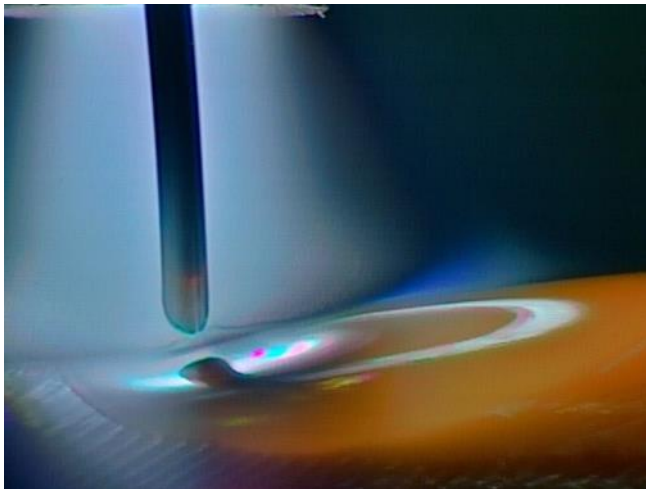
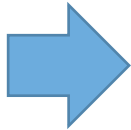
WAAM Software

WAAM process procedure

CAD model
modification to
preforms

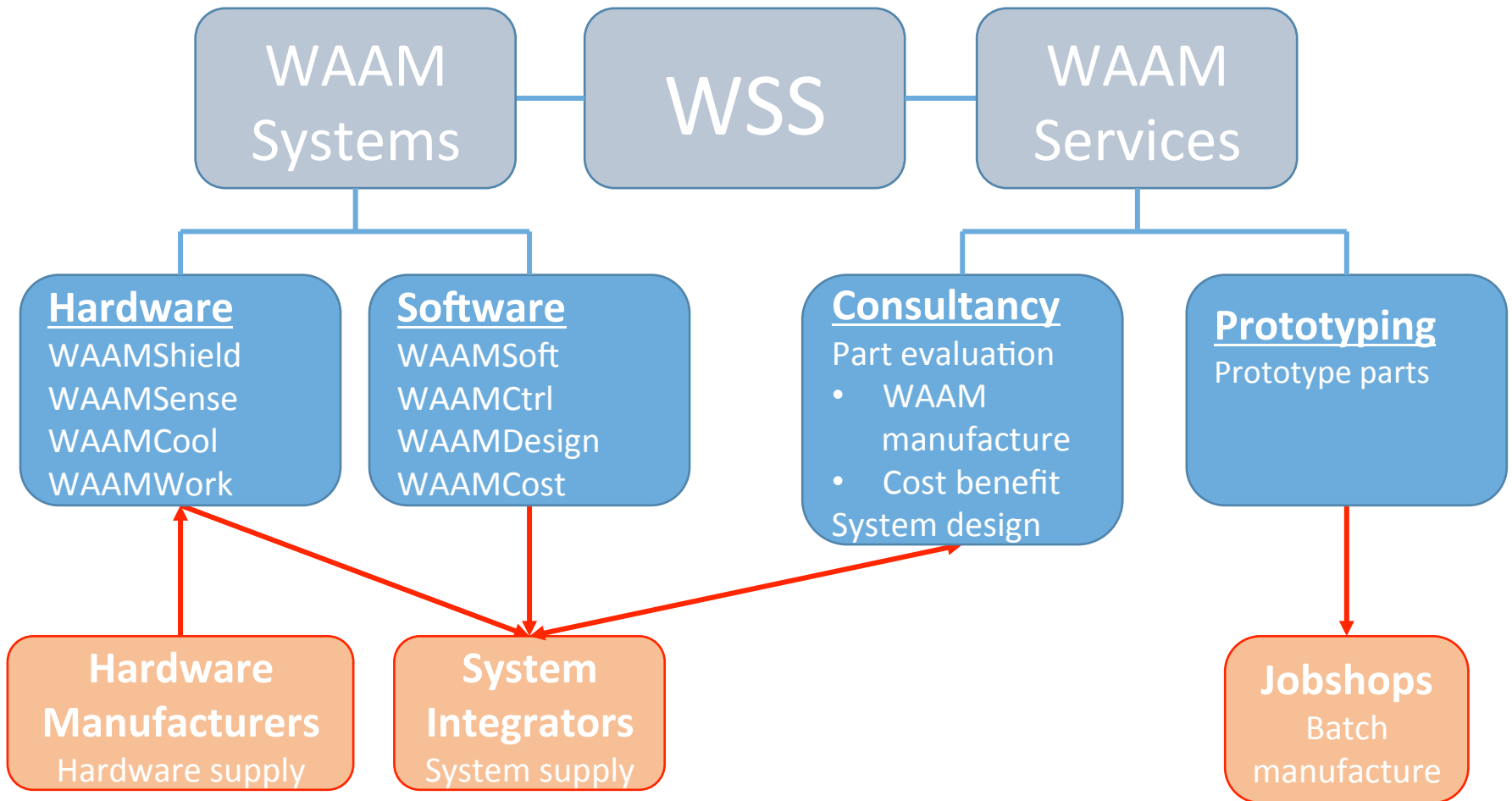
Path planning and
post-processing
to robot/ CNC
programme

Process
monitoring
and control





WAAM Commercialisation – WAAM Systems and Services (WSS)





Potential WAAM systems under discussion

Type	System	Functionality	Approximate Sale Value	Likely sector
A	Very low cost CNC	<ul style="list-style-type: none"> Cheap analogue power source Low cost CNC Limited software functionality Limited build volume 	£10k - £30k	3D printing, enthusiasts, education
B	Low cost-high end robot + digital power source	<ul style="list-style-type: none"> Al/Steels/Inconel/ Etc. - GMAW Simple parts, shapes and features Medium software functionality (maybe bespoke) 	£60k – £300k Hardware typical: £120k Software depending on functionality can cost up to £100k	General engineering, oil & gas, defence,
C1	High cost-high end robotics system (1 or more robots)	<ul style="list-style-type: none"> Plasma based including Ti 1 or more robots Multiple processes - Integrated cold work + machining + metrology + NDT High software functionality 	£200k – £600k For 2 robots: £250k and includes machining heads and tool changers	Aerospace, high value manufacturing, energy, defence, repair
C2	Medium cost CNC based system	<ul style="list-style-type: none"> Limited build volume (1 m³) Limited functionality Plasma based including Ti High software functionality 	£250k – £750k	Aerospace, high value manufacturing
D	High cost-high end CNC (robotic + CNC)	<ul style="list-style-type: none"> Integrated cold work + machining NDT + metrology All materials incl. titanium High software functionality 	£0.5 – £2 million	Aerospace