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**

<table>
<thead>
<tr>
<th>Design option</th>
<th>Mass (kg)</th>
<th>BTF</th>
<th>Cost (£k)</th>
<th>Cost red.</th>
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<tr>
<td>Original machined</td>
<td>20</td>
<td>12</td>
<td>16.2</td>
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<td>WAAM + machining</td>
<td>20</td>
<td>2.3</td>
<td>5</td>
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<table>
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<th>Design option</th>
<th>Mass (kg)</th>
<th>BTF</th>
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<th>Cost red.</th>
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<tr>
<td>Original, machined</td>
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<td>12</td>
<td>1.6</td>
<td>-</td>
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<tr>
<td>WAAM + machining</td>
<td>36</td>
<td>2.3</td>
<td>0.7</td>
<td>55%</td>
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</table>
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

**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

**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

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

**Design Capabilities**
- Commercial systems
- Qualified materials
- WAAM Industrial applications
- Mature WAAM

**Fully supported**
- Partially supported
- Not yet supported
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**  
  AI deposition, part and component building
- **Armando Caballero**  
  New materials
- **Thomas Kissinger**  
  On-line sensing
- **Michelangelo Mortello**  
  WLAM and WLAAM
- **Uzami**  
  Part building

**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

**Currently 29 people on programme + 3 technicians**

**Researchers Cranfield**

**Academic Cranfield**

**Students**
# WAAMMat Programme - Academic Partners

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

<table>
<thead>
<tr>
<th>Partner Type</th>
<th>Rights</th>
<th>Requirements</th>
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</table>
| Full         | • Perpetual royalty free license to all foreground IP from the core programme whilst partners  
               • **Full access to detail of all research outputs in core projects**  
               • Access to background IP needed to exploit WAAM  
               • Member of industry advisory group | • 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    | • **Visibility** of all research outputs from the core projects  
               • Access to background IP needed to exploit WAAM  
               • Member of industry advisory group by invitation only | • Contribution to the WAAMMat by for example  
               • Non-core research project sponsorship  
               • Smaller research project contribution |
# WAAMMat industry members

<table>
<thead>
<tr>
<th>WAAMMat Full</th>
<th>Associate or collaborative</th>
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<tbody>
<tr>
<td>UK International</td>
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<tr>
<td>BAE Systems</td>
<td>CCFE</td>
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<tr>
<td>Lockheed Martin</td>
<td>Volvo Trucks</td>
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<tr>
<td>Global robots</td>
<td>Delcam</td>
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<tr>
<td>NEIMM</td>
<td>Constellium</td>
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<tr>
<td>DSTL</td>
<td>Airbus Group</td>
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<tr>
<td>UTRC</td>
<td>Fanuc</td>
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<td>Glen Almond</td>
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<td>FMC</td>
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<td>Linde Gases</td>
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<td>Otto Fuchs</td>
<td>EWM</td>
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<td>Weir</td>
<td>Bekaert</td>
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<td>Norman Foster &amp; P</td>
<td>In discussion</td>
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<td>3D systems</td>
<td>Boeing</td>
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<tr>
<td>Roxel</td>
<td>Northrop Gruman</td>
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<tr>
<td>Keppel</td>
<td>Air Liquid</td>
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WAAM Basic System and IP

**Software and Process Data**
- Geometric Data Input (3D CAD)
- Feature identification
- Deposition geometries
- Build sequence
- Conversion to Layer Geometry (Slicing)
- Process Parameters
- Machine Tool/Robot Path Generation

**Intellectual Property**
- Material properties

**Basic WAAM Hardware**
- NC Controller
  - Motion System
  - Power Source
  - Material Supply

**WAAM - IP**
- Process Algorithms
- Design Handbook
- Compensation strategies
- Feature build strategies
- Additional processes

**Additional Functionality**
- Inspection (Shape/Defects)
- Finishing (Milling/Grinding)
- Additional Processes (e.g. Rolling, PDHT)
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)

**WAAM Systems**
- Hardware
  - WAAMShield
  - WAAMSense
  - WAAMCool
  - WAAMWork
- Software
  - WAAMSoft
  - WAAMCtrl
  - WAAMDesign
  - WAAMCost

**WSS**
- Prototyping
  - Prototype parts
- Consultancy
  - Part evaluation
  - WAAM manufacture
  - Cost benefit
  - System design

**WAAM Services**
- Jobshops
  - Batch manufacture

**Hardware Manufacturers**
- Hardware supply

**System Integrators**
- System supply
## Potential WAAM systems under discussion

<table>
<thead>
<tr>
<th>Type</th>
<th>System</th>
<th>Functionality</th>
<th>Approximate Sale Value</th>
<th>Likely sector</th>
</tr>
</thead>
</table>
| A    | Very low cost CNC | • 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 | • 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) | • 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 | • 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) | • Integrated cold work + machining  
• NDT + metrology  
• All materials incl. titanium  
• High software functionality | £0.5 – £2 million | Aerospace |