PROJECT FINAL REPORT

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MERLIN Project Document Reference:	DR75 MERLIN

Contents

NOMENCALTURE

AM	Additive Manufacturing
CAD	Computer Aided Design
CAM	Computer Assisted Manufacturing
CUT	Conventional Ultrasonic Testing
LMD	Laser Metal Deposition
LMD-p	Laser Metal Deposition with powder
LMD-w	Laser Metal Deposition with wire
LUT	Laser Ultrasonic Testing
NDT	Non Destructive Testing
OEM	Original Equipment Manufacturer
QA	Quality Assurance
QC	Quality Control
SLM	Selective Laser Melting
UT	Ultrasonic Testing
WP	Work Package

1. Final publishable summary report

1.1 Executive Summary

MERLIN is collaboration between six world leading aero engine manufacturers; Rolls-Royce is the coordinator, six renowned RTD providers and two intelligent SME's. The concept of the MERLIN project is to reduce the environmental impact of air transport (reduced by to fly ratios) using Additive Manufacturing (AM) techniques in the manufacture of civil aero engines. The focus was on selective laser melting (SLM) and laser metal deposition (LMD) technologies to develop and manufacture a total of 10 different civil aero engine demonstrator components. These demonstrator components were selected to give impact across a wide applications space with different performance characteristics i.e. temperature, corrosion and static/moving parts. The demonstrators were also selected to indicate impacts on material savings, other environmental and through life cycle benefits and price reductions when comparing with conventional manufacturing routes.

MERLIN's overall aims and objectives for the project duration were to develop AM techniques, at the level 1 stage, to allow environmental benefits including near 100% material utilisation, no toxic chemical usage and no tooling costs, to impact the manufacture of future aero engine components (current buy to fly ratios result in massive amounts of waste). This was supplemented by improved quality control of raw powder materials, powder recycling, topology optimised structures, post machining, repair, improved AM productivity and in-line NDT inspection for flaw detection. All of these factors could drastically reduce emissions across the life-cycle of the parts.

In general terms, tooling costs were eliminated for a large majority of MERLIN demonstrators due no requirement to produce tooling, jigs or fixtures for the SLM and LMD processes (5 of 10 demonstrators). 5 further demonstrators produced by LMD required fixtures to hold substrates. However, because the LMD process imparts little force onto the substrate during processing, other than secondary forces due to thermal expansion/contraction which can be kept to a minimum, fixturing requirements were significantly less robust and therefore, less costly, that those used for conventional machining i.e. high forces from high speed cutting tools.

Material utilisation and powder recycling has come from a number of LMD activities where MERLIN demonstrators have been manufactured with high material usage (70 – 85% for LMD-p and nearly 100% for LMD-w). Further, SLM recycling trials have shown acceptable part quality after 14 powder recycling iterations.

High specification materials including René 142 onto René N5 substrates and CM247LC by SLM, which are notoriously difficult to process due to crack sensitivity, have been successfully applied in the manufacture of MERLIN demonstrators.

Topology optimisation has been successfully carried out for two demonstrators (Blade shielding case and turbine support case) show weight reduction between 20 and 35%.

Productivity improvement, although still lacking during the AM process, has nevertheless proved to reduce lead time against conventional manufacturing by several months (Virole demonstrator by TM – see Table 2).

NDT inspection systems have been successfully developed (LUT and CUT) for inline inspection of both the LMD and SLM processes with crack detection of 66µm at a depth of 200µm possible (ideal to look between layers). Prior to MERLIN, there have been no previous attempts to develop such systems for LMD or SLM

A final project glossy brochure demonstrating key outputs of the MERLIN project is freely downloadable from the MERLIN website (www.merlin-project.eu). Within the MERLIN project, new innovative technologies and AM methods have been developed with a direct focus on industrial application, giving benefits to SME beneficiaries and end users.

1.2 Project context and objectives

MERLIN is collaboration between six world leading aero engine manufacturers; Rolls-Royce is the coordinator, six renowned RTD providers and two intelligent SME's (see Table 1). The concept of the MERLIN project is to reduce the environmental impact of air transport (reduced buy to fly ratios) using Additive Manufacturing (AM) techniques in the manufacture of civil aero engines. The focus was on selective laser melting (SLM) and laser metal deposition (LMD) technologies to develop and manufacture a total of 10 different civil aero engine demonstrator components. These demonstrator components were selected to give impact across a wide applications space with different performance characteristics i.e. temperature, corrosion and static/moving parts. The demonstrators were also selected to indicate impacts on material savings, other environmental and through life cycle benefits and price reductions when comparing with similar demonstrators produced by conventional manufacturing routes.

Table 1: The MERLIN Consortium

#	Beneficiary name	Short name	Country
1	Rolls-Royce Plc	RR	UK
2	WSK "PZL - Rzeszow" S.A.	WSK	Poland
3	Industria de Turbo Propulsores	ITP	Spain
4	MTU	MTU	Germany
5	LPW Technologies Ltd	LPW	UK
6	Turbomeca	TM	France
7	GKN Aerospace Sweden AB	GKN	Sweden
8	TWI Limited	TWI	UK
9	Fraunhofer - Gesellschaft zur Forderung der angewandten Forschung e.V. ILT	Fraunhofer	Germany
10	Association pour la Recherche et le Developpement des Methodes et Processus Industries	ARMINES	France
11	Asociacion Centro De Investigacion En Tecnologías De Union Lortek	LORTEK	Spain
12	BCT	BCT	Germany
13	University West	HV	Sweden
14	Frederick Research Centre	FRC	Cyprus

MERLIN's overall aims and objectives for the project duration were to develop AM techniques, at the level 1 stage, to allow environmental benefits including near 100% material utilisation, no toxic chemical usage and no tooling costs, to impact the manufacture of future aero engine components (current buy to fly ratios result in massive amounts of waste). This was supplemented by improved quality control of raw powder materials, powder recycling, topology optimised structures, post machining, improved AM productivity and in-line NDT inspection for flaw detection. All of these factors could drastically reduce emissions across the life-cycle of the parts.

There are many different additive manufacturing techniques available that use different raw materials (metals, polymers and ceramics) supplied in a variety of mediums (i.e. powder, jetable fluids, resin vats, sheet material etc.) and all processed/delivered by different energy sources or technologies (i.e. laser, electron beam, inkjet print head, flash lamps, extrusion head etc.). The MERLIN project focussed on metal power material processed by laser energy sources. Two AM technologies were selected (1) Selective laser melting (SLM) and (2) Laser metal deposition 'laser cladding' (LMD). In the time frame of the MERLIN project proposal (2009-2010) and MERLIN project start date (2011) these two techniques showed significant promise for metal aerospace applications, allowing for complex geometries for advanced product functionality in a wide range of complex alloy materials; allowing entirely new product designs currently not possible to manufacture using conventional processes such as casting and machining. In particular, LMD also cut across applications for OEM part manufacture as well as repair of damaged components.

In both SLM and LMD the processes starts by numerically slicing a 3D CAD model into a number of finite layers. For each sliced layer, a laser scan path is calculated which defines both the boundary contour and some form of fill sequence, often a raster pattern. Each layer is then sequentially recreated by one of two techniques:

In LMD, a weld track is formed using metal powder as a filler material which is fed, through a nozzle, to a melt pool created by a focused high-power laser beam (high power CO2 or fibre laser). The powder, transported into the laser beam via an inert gas carrier, is focused into a small area in the vicinity of the laser beam focus (powder-gas beam focus). By traversing both the nozzle and laser, a new material layer develops with precise accuracy and user-defined properties. The application of multi-layering techniques allows 3D structures to be created (see Figure 1a).

In SLM, a powder layer (typically 50μm in thickness) is spread uniformly by a wiper into the build envelope; on top of a piston assembly. A high power-density fibre laser with a typical 40μm beam spot size scans the power layer surface and fully melts the pre-deposited powder layer in areas defined by the numerical sliced layer data. The melted particles fuse and solidify to form a layer of the component. Multiple layering techniques allow repeated repetition of the process until all layers have been recreated and fused together (see Figure 1b).

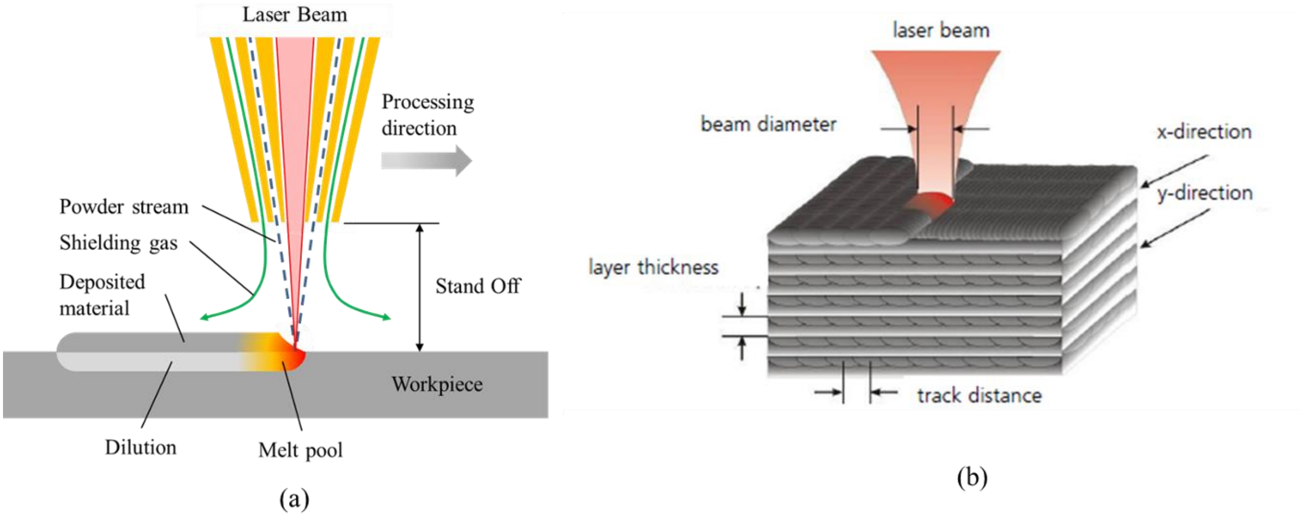


Figure 1: Schematics of the (a) Laser Metal Deposition process and (b) Selective Laser Melting process.

The advantages of using LMD and LMD, supplemented by post machining and inline inspection technologies, to reduce the environmental impact of civil aero engine manufacturing include:

- **Material utilisation** - The production of aero engine components traditionally creates a massive amount of waste, e.g. through machining from solid blocks. 'Buy-to-fly' ratios of 10 to 1 are not uncommon. AM techniques have the potential to approach zero waste through close to 100% material utilisation and the use of recycling within the processes. This results in a reduction in emissions because over 75% less raw material is consumed.
- **Reduction in Tooling**: In general terms, tooling costs can be eliminated in SLM and largely eliminated in LMD. LMD can sometimes still require a need for fixturing. However, because the LMD process imparts little force onto the substrate during processing, other than secondary forces due to thermal expansion/contraction which can be kept to a minimum, fixturing requirements are less robust and therefore costs can be considerably reduced over those manufactured for conventional machining i.e. high forces from high speed cutting tools.
- **Design optimisation** - AM is a key enabler for design or topology optimisation because the additive nature of the techniques allows very complex parts to be created. This takes two forms:
    - Design for light-weighting. This can reduce the weight of parts typically by up to 40%. A 100kg saving in material is equivalent to a reduction of 1.33Mn tonnes of CO_2 equivalent emissions across the life of an aircraft.
    - Design for performance rather than manufacturing. This has the potential to significantly improve the performance of aero engines with a corresponding reduction in emissions.

- **Reduction in toxic chemicals -** AM techniques do not directly use toxic chemicals in any measurable amount. This is a direct benefit against processes such as machining. For example in the German machining industry 75,000 tonnes of cooling lubricants were consumed during a single year.
- **Part transportation**. The transportation of materials and parts to different facilities in the supply chain can result in significantly more emissions than the production of the part itself. AM can reduce this by reducing the length of the supply chain and reducing the weight of the components that need to be transported. It also results in less tonnage of raw material transported per component.

Project Objectives

The MERLIN consortia have identified the following areas where a progression of the state-of-the art is needed for significant industrialisation considerations of AM technology:

- Productivity increase.
- Part design or topology optimisation.
- Powder recycling validation.
- In-process NDT development.
- In-process geometrical validation.
- High specification materials process development.

With the above bullet points taken into consideration, the MERLIN project is focussed on achieving eight key objectives (see Figure 2):

- **Productivity increase.** Improve the environmental case for additive layered manufacturing by achieving a step change improvement in productivity of the LMD and SLM process; Target: $50cm^3$/hr for Inconel alloys in SLM and 10kg/hr for Inconel alloys in LMD.
- **Design or Topology optimisation.** Design optimisation for light-weighting and performance benefits; Develop software capable of topology optimisation strategies including methodologies that will reduce part weight by up to 25%.
- **Powder recycling validation.** Validate the use of recycling, through the testing of material created using recycled powder, with a maximum of a 3% drop off in properties
- **In-process NDT development.** Develop an in-process Non-Destructive Testing (NDT) system, capable of detecting 200 micron pores in 500 micron thick deposits, for the Laser Metal (LMD) Process, to ensure deposited component quality. This will allow standards to be drafted that will allow the use of LMD in advanced production applications
- **In-process geometrical validation.** Develop a closed loop process for geometrically controlled LMD processing and evaluate the potential read across for SLM
- **High specification materials process development.** Improve the state-of-the-art in the LMD and SLM processes by depositing highly crack susceptible, high temperature performance alloys, such as TiAl, Mar-M-247 and Inconel, through the use of highly sensitive process monitoring and control, and advanced thermal management systems
- **Product life cycle assessment.** Carry out a study into the benefits of using AM through the part lifecycle with respect to the amount of toxic chemicals, water and other consumables
- **Technology Demonstration.** Provide at least three technology demonstrators that highlight the advantages of AM techniques, i.e. light-weighting, advanced geometries and high performance alloys

The efficient implementation of the MERLIN project was carried out over 6 technical work packages, 1 dissemination and exploitation work package and 1 project management work package. The main aims of the work packages are listed below with partner responsibilities in brackets. This report will show that each of the project objectives has been fully completed. The only exception is LMD productivity improvement where productivity proved to be restricted by demonstrator geometric requirements (see Section 1.3.1).

WP1 Project definition and specification: RR will drive this work package which will define the work to be carried out in *MERLIN*. This will be based on the fundamental process development required to develop the technologies to the required levels, but will also include work that looks at through life-cycle analysis to ensure that the benefits are justified.

WP2 Shape: ARMINES will lead this WP and will focus on shape optimisation of selected demonstrators. There will be three focussed themes (1) Topology Optimisation (ARMINES), (2) Modelling (FRC) and Geometrical Evaluation (BCT).

WP3 Process development: ILT will lead this WP and will focus on process development to improve the quality and productivity of AM. This will include closed loop control of part dimension (BCT with ILT).Support will be given by all the RTD performers backed up by the OEM's and other partners.

WP4 In-process NDT: TWI will lead this WP and will focus on 'in-process' quality control developments such as LUT NDT for LMD (TWI with RR) and conventional UT for SLM (MTU).

WP5 Post-processing: HV will lead this WP and will involve input from all partners focussed on post-processing issues testing (i.e. materials testing), heat treatment and the validation of recycling.

WP6 Technology demonstration: TM will lead this work package and will focus on the management of all MERLIN level 1 demonstrator activity. This WP will also document the environmental and business case for validation of the developed technologies and methods. All partners will be involved in this WP which will contribute significantly to project exploitation and dissemination.

WP7 Management: RR is the *MERLIN* coordinator, supported through project management and administration by TWI. This WP involved coordination of the knowledge generated in the MERLIN project as well as administrative and financial management.

WP 8 Exploitation and dissemination: BCT will lead this WP and will focus on ensuring appropriate dissemination and exploitation activity and ensuring the deliverables and outputs demonstrate a step change in Additive Manufacturing capability and have a real and definite impact on the greening of civil aero engine manufacturing.

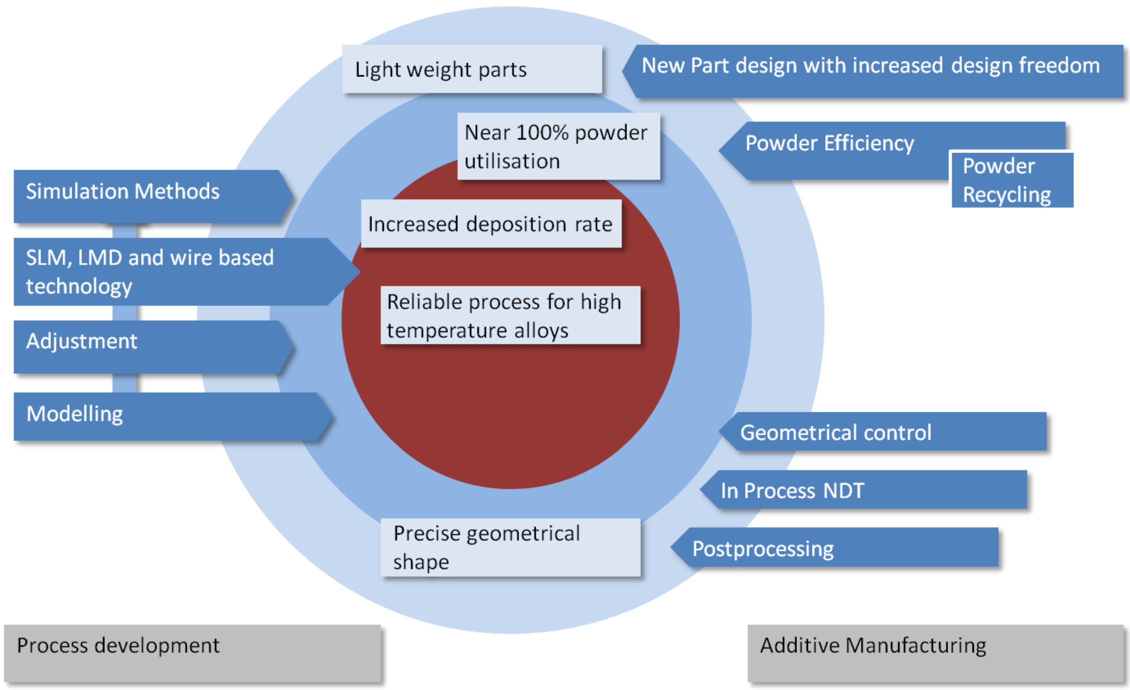


Figure 2: Basic modules and objectives of the MERLIN project

1.3 Science and Technology Results

This section describes the key science and technology results disseminated from the MERLIN project. The purpose is to give a summary of results that have been both presented at conferences and public workshops and more generically, from technical achievements documented in the MERLIN deliverable reports. The results summary will be presented in WP order in the following subsections. However, because there is a large dependence of project understanding and key dissemination activity surrounding the demonstrator activity, WP6 will be summarised first.

1.3.1 WP6 - Technology demonstration

Technology demonstration - Environmental and through lifecycle evaluation
WP6 was dedicated to producing a number of generic demonstrators and aero engine components to demonstrate the benefits of the additive manufacturing technologies being developed within MERLIN. The demonstrators will also indicate impacts on material savings, other environmental and through life cycle benefits and price reductions when comparing with similar demonstrators produced by conventional manufacturing routes. Both deliverables for WP6 were fully completed and submitted (D6.1 Demonstrator Specifications; D6.2 Demonstrator specifications report).

End users of the MERLIN consortium were asked to complete a questionnaire which characterized and explained their potential applications to be considered within the MERLIN work programme.

The end users, through a series of one to one meetings, identified beneficiaries with the necessary expertise, skills and hardware to manufacture, re-design and/or test the materials and demonstrators. This created deliverable D1.1 The Merlin Specification document and involved input from all beneficiaries.

The demonstrators were divided into 3 tasks related to:
- Task 6.1 Creation of demonstrator components to highlight weight saving
- Task 6.2 Creation of demonstrator components with advanced geometries for function, repair and recycling
- Task 6.3 Demonstrators utilising high performance alloys

Hence, the objectives related to each of the demonstration areas are summarized below:

- Task 6.1 (Creation of demonstrator components to highlight weight saving)
    - Design innovations related to the use of additive manufacturing
    - Benefits of the material saving aspect of additive manufacturing during both manufacturing and life cycle of the engine or part (CO_2 impact, and fuel efficiency savings due to engine weight reductions)

- Task 6.2 (Creation of demonstrator components with advanced geometries for function, repair and recycling)
    - Design innovations related to the use of additive manufacturing
    - Benefits of using additive manufacturing in terms of function (for example rate improvement) and manufacturing costs or cycles

- Task 6.3 (Demonstrators utilising high performance alloys)
    - Progress of the state of the art since the beginning of the project on the knowledge of manufacturing of high performance alloys.

The overarching objective across all tasks was to reduce the environmental impact of the manufacture and use of the demonstrators i.e. reduced lead time through reductions in the amount of material to be machine,

Initially, 14 demonstrators were highlighted which was eventually reduced to 10 due to issues related to the complexity of manufacture with the given materials, i.e. not suitable for additive manufacture, within the time frames of MERLIN. Table 2 summarises the final 10 demonstrators and Table 3 summarises the advantages gained by the MERLIN approach. Additional advantages, for example in-line NDT and powder recycling, all of which utilised the MERLIN demonstrators in Table 2, will be discussed throughout this report.

<u>Life Cycle Analysis</u>

The subject of LCA was mentioned in the Merlin DOW and linked to the demonstrators (WP 6). Materials savings through ALM and particularly in SLM was demonstrated in WP5 but energy utilisation efficiency aspects are touched in WP6. In the course of the project, ARMINES conducted a LCA (which formed part of A PhD thesis) to look at the electrical energy efficiency of the SLM densification ("wall plug to component") together with the primary energy content (electrical power plant level) and CO_2 emissions which can be deduced according to the local distribution of electricity generation among energy sources.

The second part of the LCA was to compare the energy efficiency of production of a component along two routes, SLM, based on own work, and foundry based on previous experiences of ARMINES (virtual foundry) and also on operational data on energy consumption and production in one full week of operation.

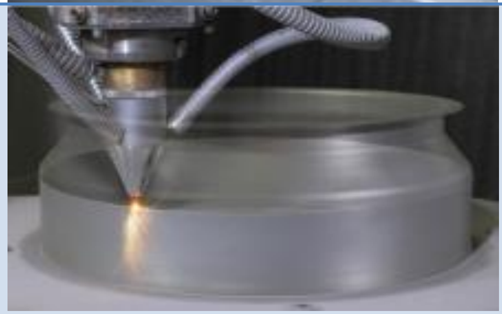
The SLM route offers the attractive advantage of close to perfect powder utilization (as suggested by multiple results within MERLIN) which, even for the most efficient laser and most efficient scanning strategy, is offset by a poor electrical energy efficiency (see MERLIN D6.2 report). Combining the two effects, SLM and

Table 2: The MERLIN Final Demonstrator List.

MERLIN - WP6 DEMONSTRATORS TABLE							
N°	**Part designation**	**OEM**	**Realisation**	**Process**	**Material**	Challenging **issue** (Objective)	**WP Task**
1a	Features on hot structural casing	VAC	HV	LMD-w	Inconel 718	The aim of VAC in Merlin is to compare LMD wire and LMD powder for the same feature geometries. Comparison will be performed regarding : • Cost equipment • Cost manufacture (sequence list) • Producibility • Quality • Properties • Robustness of method/process • Additional items for comparison might be added	T6.1
1b	Same as **1a**	VAC	TWI	LMD-p	Inconel 718	See Demonstrate 1a	T6.1
4	Combustion chamber	TM	TWI	LMD-p	Hastelloy X or Inconel 718	• This part is generally made by welding metal sheets, with forged parts • During prototype iteration forming tools process requires several months for manufacture at high cost. Manufacturing time needs to be reduced from several months to 1 month. • This part is really complex, with thin walls, and complex 3D shape.	T6.2
6	Extension of blade root	MTU	ILT	LMD-p	IN 718 on Sx	No current method of manufacture	T6.2
7	Top Core Vane of an OGV	ITP	LORTEK	LMD-p	Inconel 718	Actual manufacturing process very complicated Reduced Lead time requirement. • The use of LMD-p should allow to reduce lead times Total height of the part to be deposited is 15 to 20 mm.	T6.2
8	Boss on case	RR	TWI	LMD-p	Inconel 718	Reduced cost, reduce waste material and lead time • The case wall is 3mm thick by c. 600 mm dia. X c 600mm high • The cases are currently machined from solid ring rolled forgings. This crease large amounts of waste material • Boss to be deposited onto think substrate casing to reduce amount of machining and waste material	T6.2
9	Diffuser inner case	ITP	LORTEK	SLM	Inconel 718	Rapid manufacturing will allow to test many part design, during engine design process, in order to improve geometry of the part	T6.2

MERLIN - WP6 DEMONSTRATORS TABLE							
N°	**Part designation**	**OEM**	**Realisation**	**Process**	**Material**	Challenging **issue** (Objective)	**WP Task**
						before the expense of casting tools At the development stage, the design changes require short term responses in manufacturing times. Current casting rapid prototyping techniques are not fast enough to comply with the shorter and shorter delivery times required.	
10	Low Pressure Turbine Hard Facing of labyrinth seals	MTU	ILT	LMD-p	CBN or CBN / TiAl	Reduced cost and lead time • Low Pressure Turbine (LPT) blade • Current method of manufacture is plasma spraying • Expensive masking.	T6.3
11	High Pressure Turbine Repair	MTU	ILT	LMD-p	Single crystal Rene 142	Current repair restricted to tip of blade	T6.3
12	NGV	TM	ILT	SLM	Inconel 738	Rapid manufacturing will allow to test many part design, during engine design process, in order to improve geometry of the part before to make casting tools • High pressure Nozzle Guide Vane is situated just after the combustion chamber and is dedicated to guide the hot gas on the HP turbine wheels. • This part is generally made by foundry, but during prototype iteration the casting process takes a long time and is resource hungry. • Additive Manufacturing processes will be developed to reduce the time during prototype testing. • This part is really complex, with thin wall and complex 3D shape.	T6.3

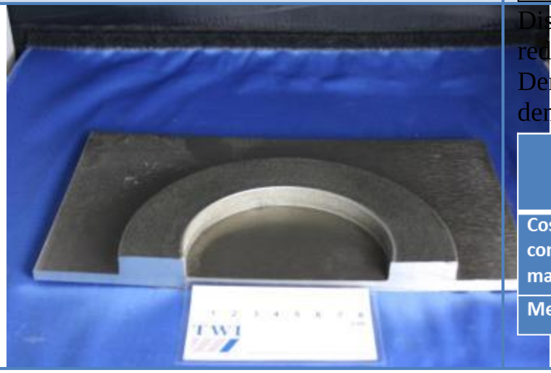
Table 3: MERLIN demonstrator results.

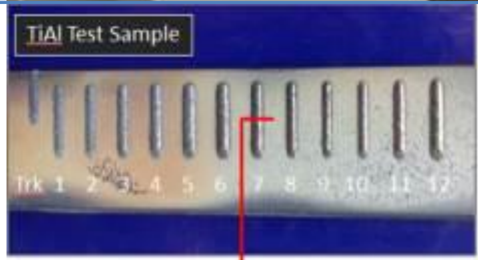
N°	Part designation		Progress beyond state of art
1	Features on hot structural casing		A simplified comparison between a fabricated structure and machining from a forging has been made by GKN based on the results from Demo 1a and 1b. A substantial cost down potential, mainly due to reduced input material (by replacing the oversized forging envelope with near-net sheet metal and LMD) is very achievable For LMD-w almost 100% of the wire additive is utilised, while 70% powder utilisation was seen by LMD-p. For LMD-p crack free deposition was achievable Deformation measure of the back side of the sheet metal casing directly below the stiffener shows a sinking in of 1.7 mm for the LMD-w case and 0.9 mm for the LMD-p case.
2	See demonstrator **1a**		See demonstrator **1a**
4	Combustion chamber		The thin walled Virole demonstrator for TM was produced using LMD to required NET shape (wall thickness 0.8mm ±0.1mm). This was achieved by the development of novel 5 axis CAM software to generate a NC tool path that allowed direct CAD to part manufacturing through adaptive slicing. Part measurement by TM show that the LMD process can obtain the same geometrical accuracy than with conventional manufacturing scheme. The lead time for conventional manufacture (10 months) was reduced to 1 month (from design to part). Cost saving through reduction of tooling €50k Significant material reduction 1.2Kg powder used compared to 45KG powder requirement for SLM

<table>
<tr><th>N°</th><th>Part designation</th><th></th><th>Progress beyond state of art</th></tr>
<tr><td>6</td><td>Extension of blade root</td><td></td><td>The residual stresses were measured by hole drilling method just after LMD-p and also after the standard heat treatment.
After the LMD process residual stresses of up to 600 MPa are observed in the build-up direction.
After the standard heat treatment the residual stress level is reduced to less than 100 MPa.</td></tr>
<tr><td>7</td><td>Top Core Vane of an OGV</td><td>
</td><td><table>
<tr><th>Conventional forging process</th><th>LMD-powder</th></tr>
<tr><td>The forging part has excess of stock material that has to be further electrochemically machined to the final drawing requirements.

Total raw material: approx. 12.2 kg</td><td>The part could be manufactured starting from a shaped sheet, being able to be manufactured the top and the bottom by LMD-p

Shaped sheet => approx. 0.5 kg
Powder to build the top and the bottom by LMD-p => approx. 0.8 kg

Total raw material: < 1.5 kg</td></tr>
</table></td></tr>
<tr><td>8</td><td>Boss on case</td><td></td><td>Distortion in substrate reduced from 7mm to 3mm in 4mm thick substrates and reduced further to 2.5mm in 6mm thick substrate.
Density of deposited from a previous study was increased from 96% dense to >995% density.<table>
<tr><th></th><th>Conventionnal processing</th><th>LMD-P</th></tr>
<tr><td>Cost for conventional manufacturing</td><td>€40k -€60k</td><td>€20k - €40k</td></tr>
<tr><td>Metal wasted (kg)</td><td>1500</td><td>240</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>N°</th><th>Part designation</th><th></th><th>Progress beyond state of art</th></tr>
<tr><td>9</td><td>Diffuser inner case</td><td></td><td><table>
<tr><th></th><th>Conventional casting process</th><th>SLM</th></tr>
<tr><td>Precision</td><td>The casting part has excess of stock material (Fig 13a) in the flanges that has to be further machined to the final drawing requirements</td><td>The part is manufactured to near net shape</td></tr>
<tr><td>Raw material</td><td>1494g</td><td>957g</td></tr>
<tr><td>Lead time</td><td>9 months</td><td>2-3 weeks</td></tr>
</table></td></tr>
<tr><td>10</td><td>Low Pressure Turbine Hard Facing of labyrinth seals</td><td>
</td><td>Within trials conducted within MERLIN, ILT found parameters which allow to obtain crack free samples in TiAl. However, no complete demo part has been manufactured during MERLIN project because of problems with the heating system</td></tr>
<tr><td>11</td><td>High Pressure Turbine Repair</td><td></td><td>The implementation of the heating was not feasible during timeframe of the project for repairing real parts. So a demo part has been repaired but the replacement part is not made of Rene142 but of IN718. MERLIN has shown that the complex geometry of this part is feasible by SLM.</td></tr>
</table>

N°	Part designation		Progress beyond state of art
12	NGV		The manufacturing time for one demo part is approx. 100 hours compared to 10 months for conventional manufacturing by casting: ✓ Directly, because the time to supply castings is replaced by having raw powder material ✓ Indirectly by eliminating the required time for manufacturing the tools necessary to produce the parts by casting Tooling costs have decreased from approx. 100K€ to 1K€. The buy to fly ratio in SLM parts is nearly 1 From a technical point of view, ILT has developed parameters that allow the user to obtain parts with a small crack formation inside the part volume. The cracks have a small size of <200 µm and a low crack density.

casting are rather close in calculated melting energy content of shaping and refining (about 40 kWh /kg –at best for SLM).

Poor productivities, and the high cost of inert gas powder atomization (starting from refined superalloy billets) and of powder classification (not considered in this report or only in part) however limit the interest of SLM and more generally AM to cases where the "new" technology adds an advantage (longer lifer expectancy or added functions in AM parts i.e. topology optimisation). The MERLIN project paves the way for increased SLM productivity in WP3, but increasing productivity usually means a deterioration of energy efficiency. To reduce the cost of powders, the possibility to use a revert alloy rather than a virgin one could be considered. The risks associated with recycling superalloys, rather well documented and identified thirty years ago in foundries would not be feared when dealing with low carbon grades and with cooling rates during solidification in excess of 10^5 K/s for the fine gas atomized powders usually considered in SLM. As usual the major risk in powder atomisation is non-metallic inclusions and it could be dealt with at the powder classification (sieving) stage. The advantage of SLM does not rest on the demonstrated advantage in powder utilisation, nor on a hypothetic saving in energy except for short production series, but it does on the possibility to produce structural parts that no other process can produce, especially parts involving functional aspects like efficient cooling, fluid flow and topology optimised designs.

1.3.2 WP1 – Project Definition and Specification

Within WP1 the objective was to complete deliverable (D1.1 The MERLIN specification). This outlined the overall research time plan and the development methodology for 8 sub-categories identified within the MERLIN work program (see Table 4). The MERLIN demonstrator specification (sub-category 6) was also used to specific the requirements of topology optimisation (WP2), In-process NDT requirements (WP4), and post processing requirements (WP5). The aim was to establish the industrial requirements of the end users, define the methodology for the development of the MERLIN technologies and to outline an exploitation strategy for the project results. Deliverable D1.1 was fully completed and submitted.

Table 4: MERLIN Specification Categories

No.	Category	WP or Task	Key Beneficiaries
1 2	Project Work Plan (Gantt Chart) LMD Productivity Improvement	1 3.1	All MERLIN Beneficiaries LORTEK, ILT, TWI, HV, VAC, WSK
3	SLM Productivity Improvement	3.2	ILT
4	Process Control	3.3	HV, VAC
5	Thermal Management	3.4	ILT, HV
6	3D Scanning geometrical	3.6	BCT
7	Testing and Analysis	3, 5	All WP3 and WP5 Beneficiaries
8	Merlin Demonstrators	6	All WP6 Beneficiaries

Within the first 6 months of the project the end users provided product specifications for each of the products/demonstrators they would like to benefit from the research within the MERLIN program. The specification document was then reviewed at M24 and M36 before demonstration activity started to ensure project deliverables and outputs were appropriate to meet the needs of the MERLIN project end users.

Initially 14 demonstrator parts were selected which was then reduce to 12 at M24 and then 10 at M36. Reasons for the reduction stemmed from difficulties to either manufacture the demonstrator geometry, to process the required material to specifications or applications suggested by the end users were considered not suitable for AM because of economic viability.

1.3.3 WP2 – Shape

Topology Optimisation, Modelling and Validation

This work package was separated into three tasks:

- Task 2.1: Topological optimisation methodology (ARMINES)
- Task 2.2: Modelling of residual stresses and distortions (FRC)

Both deliverables for WP2 were fully completed and submitted (D2.1 Topology optimised part creation report; D2.2 Distortion modelling report).

Task 2.1: Topological optimisation methodology

Topological optimisation, i.e. lightening a structure without sacrificing its mechanical performance is the primary concern of Task 2.1. The two demonstrator components used in the study (and described below) were not included in the MERLIN demonstrator list (Table 2) because a full demonstrator was never manufactured.

- **Blade shielding case (ARMINES and TM)**: Objectives to modify the shape and structure of a blade shielding case, a turbine engine component designed to contain turbine blades and debris in case of blade breakage (disk over-speed). The aim of this structure adjustment is to lightweight the complete part while keeping the containment capacity at the same level. Among the various additive manufacturing processes considered within Merlin, Selective laser melting (SLM) was chosen to manufacture the complete blade shielding case (BSC).
- **Turbine support case (ARMINES and WSK):** Topological optimization of a simple case boss has been conducted on a turbine support case (TSC) segment. The methodology used by WSK to manufacture the boss of the TSC was laser metal deposition (LMD-w,-p).

Blade shielding case

Different constant-section structures and periodic structures (see Figure 3) were compared. From the results a first selection was made of the four best geometries before impact tests. Some of these structures are inspired by a bibliographical review.

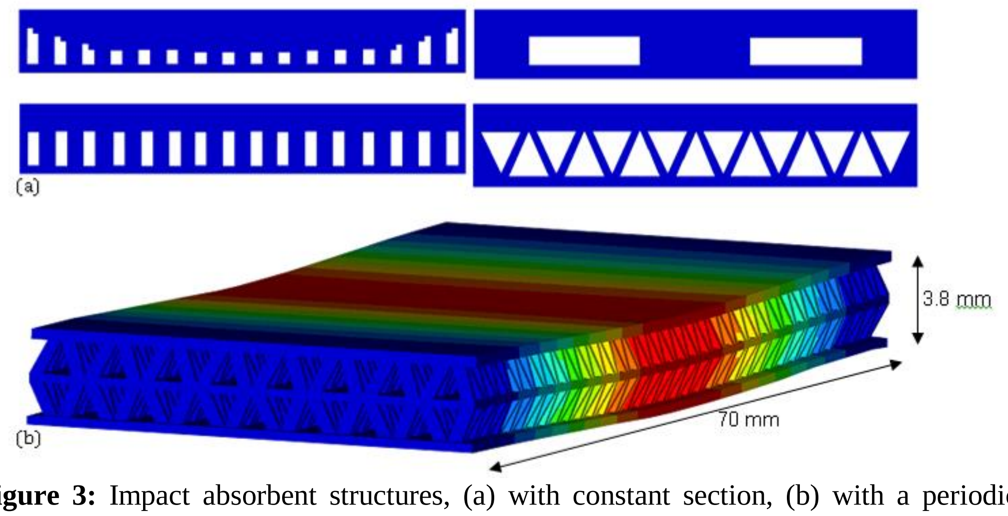


Figure 3: Impact absorbent structures, (a) with constant section, (b) with a periodic structure pictured in flexion calculated with Radioss code. Colour code refers to relative displacement.

TM designed an original technological specimen to compare the performance of several concepts for the blade shielding case applications through a numerical model of the structural analysis. Following simulation behaviour by ARMINES of each concept under static loads, TM undertook the extension of the comparison of the different geometries under dynamic loading. Two types of loadings, a quasi-static load at the centre of the specimen, and an impact loading were simulated. Quasi-static analysis is performed with ANSYS and the impact simulation is made with LSDYNA. The mesh used is identical for both types of analysis, linear features and at least 3 elements in thickness. The material simulated is Inconel 625. The specimen used for this study is presented in Figure 4

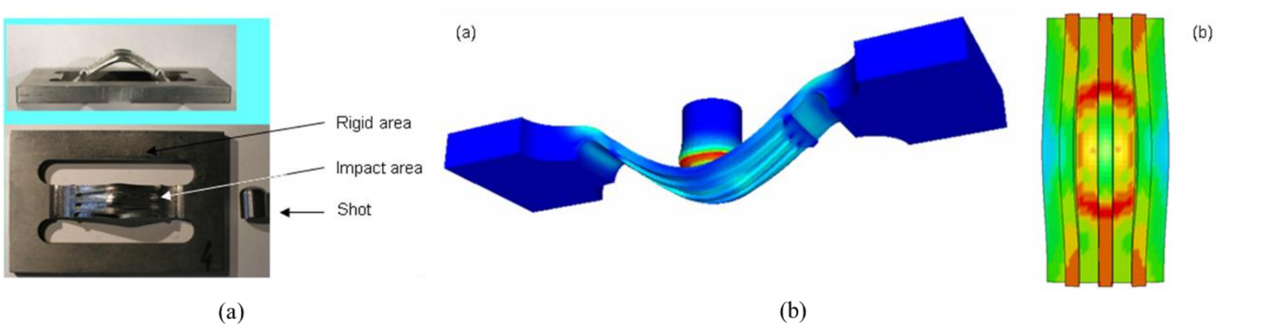


Figure 4: (a) Inconel 625 impact test sample manufactured conventionally and subjected to the impact and (b) results of LSDYNA. (a) Simulated geometry after symmetrical expansion, (b) example of the plastic strains at the maximum deformation time.

The results allowed comparisons between the stiffness, the stress fields and the maximum dynamic displacement for the evaluated concepts. This study makes possible the selection of four designs that are manufactured and evaluated by experimental impact tests.

Turbine support case

Topological optimisation of a simple case boss has been conducted on a turbine support case (TSC). WSK Rzeszow is interested in weight reduction for turbine support case bosses and also in the structural integrity and manufacturing quality after LMD and machining. So an original technological specimen has been designed to compare the performance of several concepts. During this period a numerical study has been finished in WSK to evaluate different concepts.

The results (see Figure 5) allowed comparisons to be made between the dimensions and the stress fields between each concept evaluated. This study makes possible the selection of designs that will be manufactured with reduce weight and buy to fly ratios.

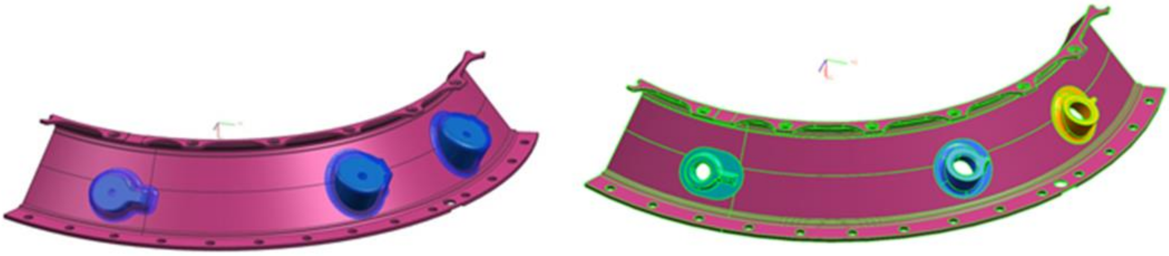


Figure 5: Flange with cone and added bosses after optimisation.

Task 2.2: Modelling of residual stresses and distortions

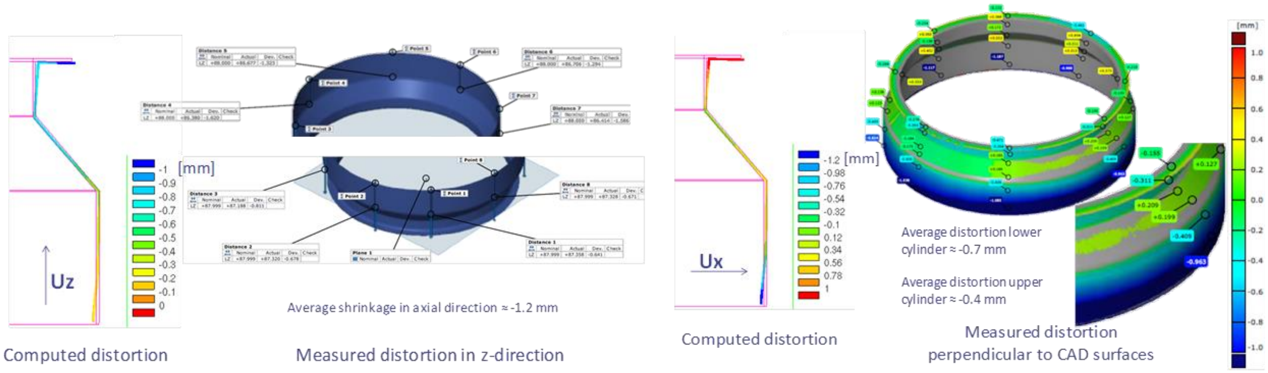
Task 2.2 involves the modelling and simulation of shape distortion during the additive manufacturing processes for Selective Laser Melting (SLM) and Laser Metal Deposition (LMD). The purpose was threefold; (1) to replicate the thermal and mechanical effects during laser additive manufacturing processes by means of modelling techniques, (2) to determine the final shape of components after additive manufacturing processing of metal powder and finally (3) to identify process specific possibilities to reduce shape distortions of final structures. Initially basic investigations of the process effects were performed on test specimens and a parametric/sensitivity analysis in regards with the application of the suitable reduced modelling approach were performed. Hereby, the distortion results accuracy by varying test components' thicknesses were evaluated. Additionally, the influence of different powder type in the distortion results for identical component geometries (twin cantilever) was investigated. Furthermore, a special focus was placed in the adaptation of the developed modelling methods, beside the simplified demonstrator structure (twin cantilever geometry), on praxis-relevant aero engine components. For this purpose two components have been selected in consultation with the MERLIN beneficiaries, and especially the end users, which were manufactured out of IN 718. These were the following:

- Demonstrator 4: an axis symmetrical Virole component manufactured by means of LMD/powder in collaboration with TWI;
- Demonstrator 12: A 3D blade of a nozzle guide vane manufactured by means of SLM in collaboration with Fraunhofer ILT and Turbomeca.

These activities were performed as planned in the WP2, Task 2.2 by FRC with the contribution of all involved partners, namely ARMINES, Fraunhofer ILT and TWI.

<u>Demonstrator 4.</u>

As can be seen in Figure 6, the developed FE model provides very good correlation with 3D scans in the lower region of the Virole part after the cut-off operation from substrate with negative deformation, i.e. reduction of the component radius of up to 1.2 mm. Simultaneously, the measurements demonstrate the same behaviour with a radius reduction of more than 1,0 mm. The results continue to indicate a very good agreement for the area of the inclined wall with no significant radial changes for both the FE model and the measured 3D scans. Then again, in the upper vertical wall the FE model fails to replicate the radial decrease and provides an increase of the radius of around 0,50 mm whilst the measurements show a reduction of the radius of around 0,35 mm. As far as the axial distortions after cut-off are concerned the overall shrinkage of the FE model is in a very good agreement with the 3D scans. A total shrinkage of more than 1,0 mm is calculated by the FE model while the 3D scans provided a total axial shrinkage of approximately 1,2 mm. Results from this work were used to develop corrective algorithms in the ToolCLAD CAM software developed by TWI.



(a) (b)

Figure 6: Virole demonstrator component distortion results in (a) *x*-(radial) direction and (b) *z*-(axial) direction after cut-off

<u>Demonstrator 12.</u>

The 3D blade of a nozzle guide vane was manufactured in a 75% reduction by Fraunhofer ILT and a 3D scan measurement of the final geometry was performed. The results of the final demonstrator part shape are presented in Figure 7. Overall, the simulated and measured shape distortion in the region of the air foil indicates comparable tendencies. Part of the higher discrepancies in other regions of the demonstrator part, as for example at the edges of the stiffening webs, can be explained through the difficulty to fit the manufactured geometry with the CAD data at the base of the components, respectively to create an identical reference area. Another reason which is also a possible source of inaccuracies for the Virole part is the fact that the material deposition during modelling take place on the already deformed component. In contrast to that, in the real manufacturing process the powder layer is each time deposited on the target CAD region, thus acting as a correction to possible distortions during SLM processing. This could be the reason why the shape distortion in the real SLM part reveals lower distortion than in the simulation.

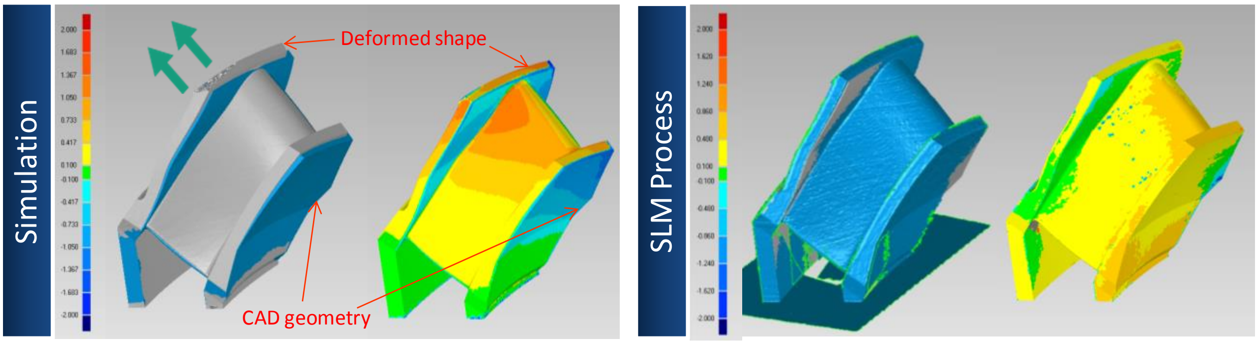


Figure 7: Comparison of the simulation results (left) with the 3D scans of the SLM manufactured 3D blade (right)

<u>**Summary**</u>

The achievements of Task 2.2 are summarised in Figure 8. Starting from investigations on small samples the complexity of parts was increased while an evaluation of possible modelling reduction approaches was investigated. Furthermore, the manufacturing chain was enhanced with post-treatment operations, i.e. cut-off of components from substrate. The influence of alternate material data as the example of IN 625 were analysed and finally an evaluation of the FE distortion results with the aid of 3D scans on real manufactured parts was carried out.

For the purposes of the demonstration of the developed modelling approach three components were utilised in close collaboration with the MERLIN partners which were manufactured out of Inconel 718:

- a symmetrical twin cantilever beam in different geometrical configurations manufactured by means of SLM in collaboration with Fraunhofer ILT;
- an axis symmetrical Virole component manufactured by means of LMD in collaboration with TWI;
- and a 3D blade of a nozzle guide vane manufactured by means of SLM in collaboration with Fraunhofer ILT and Turbomeca.

The modelling approach proposed by FRC has achieved to provide a virtual manufacturing process chain within the MERLIN project and rendered results on reverse engineering and shape distortion management of AM aero-engine components.

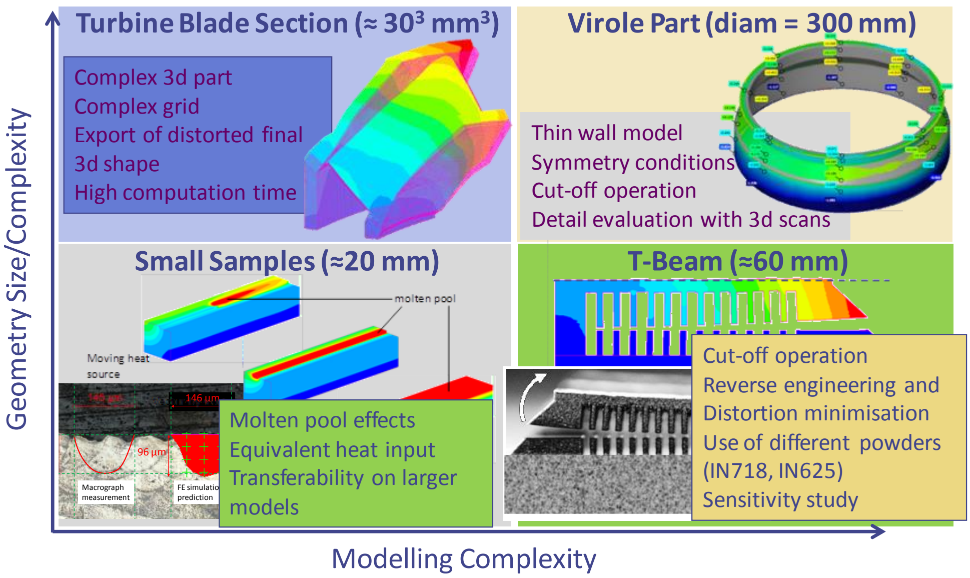


Figure 8: Summary of the activities and achievements within Task 2.2

1.3.4 WP3 – Process Development

Process development, process monitoring and control and thermal management.

This work package was separated into three tasks:
- Task 3.1: LMD Productivity improvement (TWI/GKN)
- Task 3.2: SLM Productivity Improvement (ILT)
- Task 3.3: Process monitoring and control (HV/GKN)
- Task 3.4: Thermal Management Development (ILT)
- Task 3.5: Development of more complex geometries using SLM and LMD (LORTEK/TWI)
- Task 3.6: in process geometrical control (BCT)

All five deliverables for WP3 were fully completed and submitted (D3.1 LMD Productivity improvement report; D3.2 SLM Productivity Improvement report; D3.3 Process monitoring and control and thermal management report; D3.4 Complex part creation report and D3.5 Geometrical control system report).

LMD Productivity improvement

A simplified comparison between a fabricated structure and machining from a forging is made based on the results from Demo 1a and 1b. Comparing a fabricated structure with a machined forging we see a substantial cost down potential, mainly due to reduced input material (by replacing the oversized forging envelope with near-net sheet metal and LMD). Comparing the two deposition techniques (LMD-w and LMD-p) we see that the required rigging time and post processing steps are rather similar. The difference is mainly in the build rate and feedstock material utilization. For LMD-w almost 100% of the wire additive is utilized, while 70% powder utilization is assumed in this example. Unlike the SLM processes, the scattered powder for an LMD-p process is not equally easy to collect and recycle since the process is run in open air on free-standing components.

In this project, the LMD-w process showed capabilities of approximately 10 times higher *deposition rates* than the LMD-p process. However, within the scope of this project, crack free LMD-w samples could not be obtained (although the probability was strongly reduced compared to the initial process). However, productivity rate targets of 10kg/h for LMD-w and 2-3Kg/h for LMD-p were impossible to achieve because of the types of demonstrators being investigated. For example, if a surface coating needs to be deposited onto a shaft, then deposition rates in the order of several kg/h for both processes are possible. However, when trying to achieve near net shape of more complex geometries on very thin substrates, care has to be taken when choosing the most appropriate laser power so that distortion of the substrate is kept to a minimum. Unfortunately, laser power dictates both distortion and productivity and their magnitude is largely inversely propositional. Typical deposition rates achieve for demonstrator 1a/b (see Table 2) was 0.2kg/h for LMD-p and 2.5Kg/h for LMD-w.

SLM Productivity Improvement

In order to evaluate productivity, the concept of the theoretical build rate is introduced (kg/h). Due to its theoretical nature, the concept allows to compare the productivity of different machine despite any technological differences.

The processing of the widely used nickel-based superalloy Inconel 718 (IN718) by laser powers of up to 1 kW is investigated in order to improve productivity. Using developed process parameters for this laser power range, the application of the skin-core strategy is investigated in order to maintain the surface roughness from state-of-the-art machines with laser powers of <200 W. Based on the developed high power SLM process with skin-core strategy, the feasibility of the process for manufacturing geometries of typical complexity for aerospace parts is investigated by manufacturing a segment of a nozzle guide vane (Merlin Demonstrator 12).

The skin-core strategy is required as the usable laser power cannot be increased infinitely for a constant beam diameter because of the increasing intensity at the point of processing. This intensity increase leads to a larger evaporation rate resulting in a higher incidence of spattering which has a negative effect on the process as a whole. To avoid this, the beam diameter has to be enlarged. However, enlarging the beam diameter leads to a larger melt pool which has a negative effect on the geometrical accuracy, detail resolution and surface quality of manufactured parts. This problem can be avoided if suitable beam diameters are used according to the local requirements in the part.

The approach is to divide the CAD-model of a part in a skin or shell of a specific thickness and simultaneously into a core (Figure 9 left). For both volumes different process parameters are applied. As the skin determines the geometrical accuracy and the surface quality of the part, the smaller beam diameter is used while processing it. The density of core and shell volume needs to be ≥99.5 %. A crucial point is the metallurgical bonding of core and shell volume.

The nozzle guide vane (NGV) from TM is used as complex part in a non-confidential design version. A cross section of the geometry is shown in Figure 10 pointing out the skin and core area of the part. The volume fractions of skin and core are 59.4 % and 40.6 % for a skin width of 1 mm and a skin-core overlap of 300 µm. One half of the NGV is manufactured as a segment using the skin-core strategy with a layer thickness ratio of 1:4 with an overall theoretical build rate of 15 mm^3/s. Additionally, the identical segment is manufactured completely with skin parameters, corresponding to a commercial 300 W system. An image of the manufactured part with skin-core strategy after removal from the substrate is shown in Figure 10. The overall part quality is comparable to the version manufactured with conventional parameters without skin-core strategy.

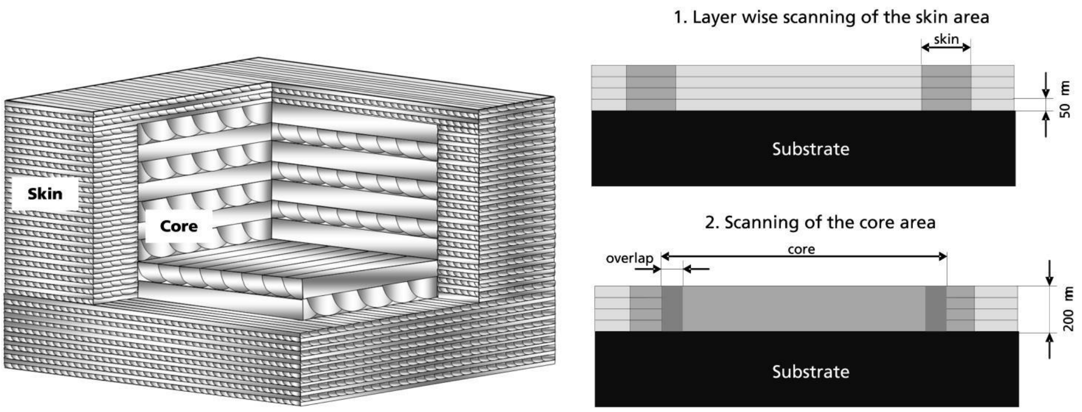


Figure 9: Schematic illustration of skin-core strategy with a layer thickness of 50 µm for the skin and 200 µm for the core, resulting in a layer thickness ratio of 1:4.

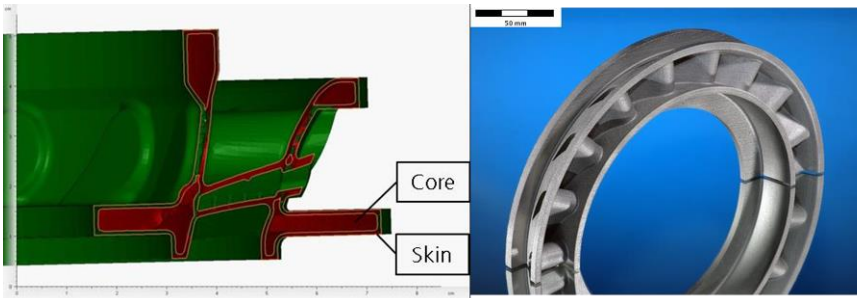


Figure 10: Cross section of NGV geometry showing calculated skin and core area/volume and Image of manufactured half of the NGV after removal from the substrate.

A study on a laboratory setup has shown the principal feasibility of the processing of IN718 with laser powers of 1 kW, but also the drawbacks of larger beam diameters with regard to the achievable surface roughness. Based on the developed process parameters for the small and large beam diameters, both parameters are successfully combined in one process using the skin-core strategy. In case of the SLM 280HL, suitable values for the skin width (1.0 mm) and the overlap of skin and core (0.3 mm) are determined for layer ratios of 1:2, 1:3 and 1:4, corresponding to a skin layer thickness of 30 µm and core layer thicknesses of 60 µm, 90 µm and 120 µm. The manufacturing of a segment of a nozzle guide vane from Turbomeca shows the possibility to apply the HP SLM process with skin-core strategy to a part with a typical complexity for aerospace applications. In comparison to manufacturing the part only with skin parameters (300 W) the primary process time is reduced by 46 % which means an productivity increase by factor the of 1.62.

Process monitoring and control and Thermal Management Development

The objective of task is related to process monitoring and control for both the SLM and LMD processes. Within this task, the following objectives are addressed by the involved partners.

- Evaluation of possible control candidates (process variables) for LMD-w and development of a process control using the most suitable candidate (HV, GKN)
- Assessment of the basic feasibility of thermography and 2D image processing for the SLM process (MTU).
- Coaxial SLM melt pool monitoring by high speed camera (ILT)
- SLM process development for IN625 (ARMINES)
- SLM process development for IN738LC (ILT)
    - Manufacturing of nozzle guide vane for rig-tests
    - Determination of minimum preheating temperature for crack free processing
    - Determine influence of heat treatment on crack formation and microstructure
    - Determine influence of preheating on distortion / residual stresses

- Experiments to improve the productivity of Direct Laser Deposition of CM247LC nickel based super alloy for use on aircraft components (RR)
    - Define process window for deposition based on design of experiments approach based on specific energy, i.e.

      $$Specific\ Energy\ (SE) = \frac{Laser\ Power\ (P)}{Track\ Spacing\ (T) x\ Track\ Speed(v)}$$

    - Examine the effects of HIP ramp rate with the objective of avoiding strain age cracking (SAC).
    - Determine the magnitudes and directions of residual stresses by hole drilling measurement.
    - Use a design of experiments (DoE) approach to optimise surface treatment parameters for reducing surface residual stresses prior to hot isostatic pressing (HIP).
    - Examine the as deposited and post HIP anisotropy SLM microstructure using electron back-scatter diffraction (EBSD)

- Development of a thermal management strategy for crack free processing of IN718 with LMD-w using high deposition rates (HV)
- LMD-p process development in IN718 for depositing of bulk material on thin sectioned substrates in IN718 – Demonstrator 4 – See Table 2 (TWI)
- LMD-p process development in IN718 for depositing of thin cross sectioned 3D geometries Demonstrator 8 – See Table 2 (TWI)

For this task the objective was not to increase the build rate of the material but to produce porosity and crack free CM247LC builds, thus increasing productivity by a reduction in non-conformance. The task from RR is allocated to task 3.2 (productivity improvement) but, due to the close relation to the process development for IN738LC, both alloys are highly susceptible to cracking, the results are presented here.

Selective Laser Melting (SLM) – Productivity Improvement for CM247LC (RR)

To achieve improvements in gas turbine efficiency and to reduce emissions the use of more heat resistant alloys is considered desirable. Their use, in combination with more complex geometries that may only be facilitated using additive manufacturing techniques (e.g. selective laser melting, SLM) could also be required. CM247LC is one such material that is used extensively in turbine applications due to its excellent stress rupture properties. However, its high γ' content means it is not generally considered a 'weld-able alloy'. This characteristic has thus far limited SLM application through the onset of in-process cracking (see Figure 11).

The aim of the work carried out in MERLIN is to determine by experiment if an optimum deposition parameter set for CM247LC can be found using a standard SLM machine, examine the root cause of cracking, investigate the use of surface treatments and to quantify textural changes that occur during heat treatment. A Design of Experiments (DoE) approach was taken to optimise the deposition parameters based on a "specific energy" approach. The optimised parameters have been used to produce crack-free test coupons following HIP and heat treatment.

Process parameters, surface treatments and heat treatments are now ready to be used for future trials on complex component geometries manufactured in CM247LC alloy.

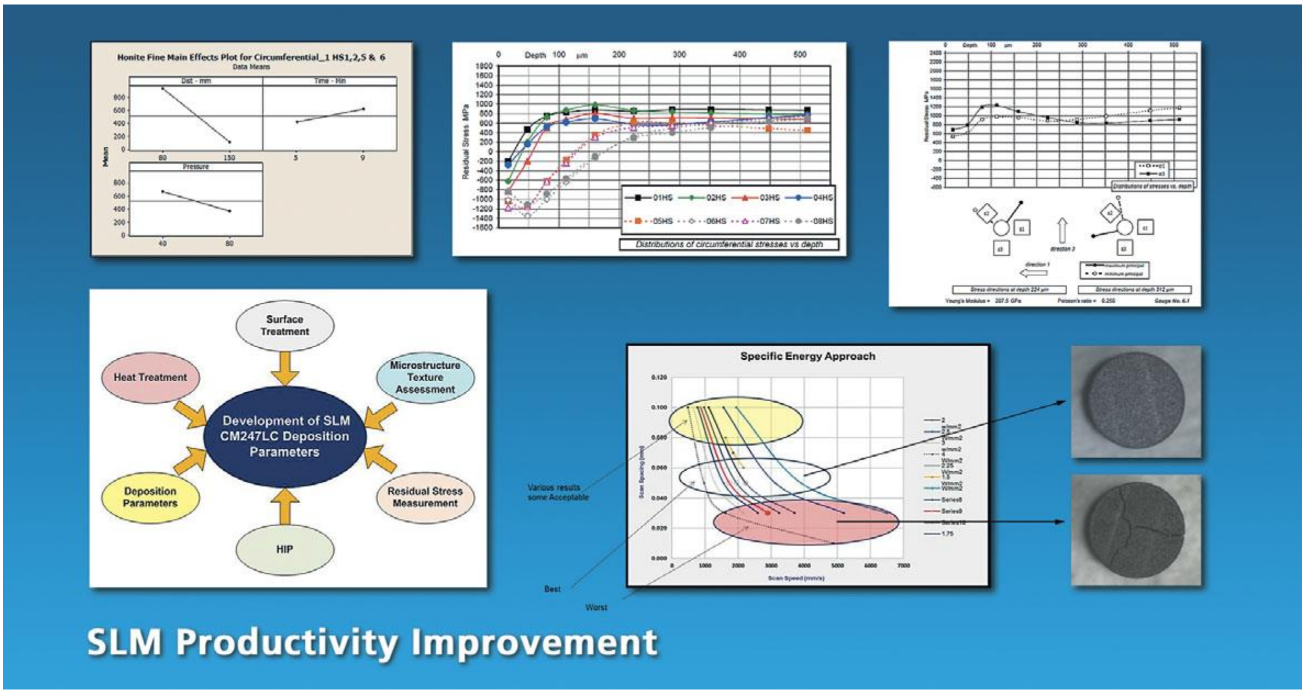


Figure 11: Productivity Improvement for CM247LC

<u>SLM Process Development for René 142 on René N5 (ILT and MTU)</u>
Ni-base superalloys have been developed specifically for high temperature applications and represent the state of the art in turbine manufacture. Especially, if developed for directionally solidified (DS) and single crystal (SX) casting, these alloys, however, show a high susceptibility to cracking during thermal processing as is the case in SLM. Additionally, the specific grain structure achieved by advanced casting processes is typically not obtained in SLM. High pressure turbine (HPT) blades in aero engines are most often manufactured as single crystals nowadays. Damage of these blades in the vicinity of the tip by burnoff, abrasion or cracking is fatal, if it is located in the blade cavity, e.g. outside the tip. As the cost of a HPT blade is considerably high, suit able repair methods are required.

SLM is considered as repair method due to the large geometrical freedom and near-net-shape manufacture. The processing of the DS alloy René 142 on a SX substrate out of René N5 by SLM is investigated at high preheating temperatures, in order to overcome the crack formation and to achieve a suitable microstructure.

Using a special setup, which allows the user to apply preheating temperatures above 1000 °C in the substrate, process parameters are identified yielding in a crack free microstructure. The grain structure exhibits directionally solidified grains which are orientated parallel to the build direction (see Figure 12). Creep properties of manufactured and heat treated samples exceed those of the widely used alloy MAR-M-247 with DS grain structure.

<u>Metastability Induced by SLM in Nickel Based Superalloys (Inconel 738 Case) (ARMINES, ILT, TM)</u>
Rapid "conduction" solidification of the liquid pool (cooling rates estimated at 106 K/s against 104 K/s for atomized powders) induces metastability. The as SLMed 738 may miss some 50% of its usual gamma prime precipitates population which may later precipitate upon heating during a post treatment. The investigation rested on the DTA (differential thermal analysis trace at 10K/s heating rate) of 0,5 gram of

Figure 12: The grain structure of for René 142 on René N5

Inconel 738 samples (SLMed, powder and cast). The quantification of metastability (% of gamma prime missing as cast for the three processing routes compared) goes through the quantification of the area under the exothermic event between 500 and 600°C in the thermograms and through thermodynamic calculation (using Thermocalc® and TCNi7 database). The evolution of the fine microstructure (see Figure 12) and of the micro hardness of the SLMed material when heated as in the case of interrupted DTA tests supports the interpretation proposed on the basis of DTA results for the three processing routes compared in DTA.

The quantification of metastability and of the return to equilibrium is a rather original finding and the methodology followed to demonstrate and quantify Metastability may apply to other ALM fabrications, LMD for instance. Suggested exploitation of metastability: one more degree of freedom to handle the case of internal stresses and damage during SLM fabrication of Inconel 738 with a moderate preheating temperature. Also the post SLM heat treatment may be optimized to obtain different final gamma prime precipitation microstructures and the proposed methodology helps planning the optimization procedure.

Extension of Blade Root out of LEK94 with Inconel 718 by LMD-p (ILT and MTU)

Low weight and high strength at the same time are typical requirements for components in aero engines. Combining two materials in one component is an approach to address these requirements and to enhance the overall performance by increasing the components load capability, reducing its weight or increasing its high temperature strength. In order to combine different materials, a fusion process is necessary and welding being a common method for this task. Unfortunately promising material combinations are not weldable by standard methods up to now.

The direct welding of a LEK94 single crystal (SX) component to an Inconel 718 component is currently not possible, so that a two step approach is investigated. In the first step a volume of Inconel 718 is built onto the SX component by Laser Metal Deposition with powder (LMDp), which serves as an interface for the second step. The development of the LMD-p process parameters is split into parameter settings for the bonding of Inconel 718 to the SX-material and for the bulk interface volume. The main task is to develop process parameters for a sound bonding without crack formation or lack of fusion.

The actual bonding of the main components is performed in the second step by welding the Inconel 718 interface of the SX-component to the Inconel 718 base component by a state of the art process like electron beam welding.

A sound bonding of Inconel 718 onto LEK94 by LMD-p is achieved with a parameter set which keeps the melt depth below 0.4 mm. For the bulk interface volume above the bonding layer process parameters with a higher build rate are determined to reduce the total build time. Using the determined process parameters, test samples for material testing were manufactured and the root of a LEK94 blade was extended with an Inconel 718 volume (see Figure 13).This work culminated in the manufacture of MERLIN demonstrator 6 (see Table 2).

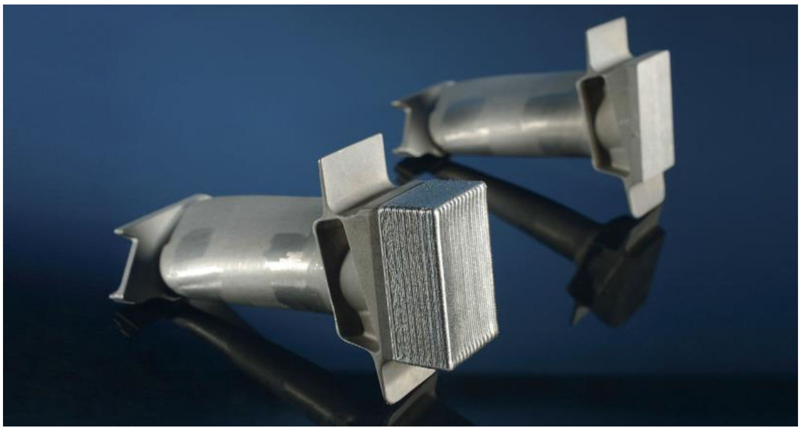


Figure 13: Extension of Blade Root out of LEK94 with Inconel 718

SLM Process Development for Aero Engine Components in IN 738LC (ILT and TM)

The powder-bed based additive manufacturing (AM) process Selective Laser Melting (SLM) enables users to manufacture complex parts out of various metal alloys. The Ni-base superalloy IN 738LC has been developed specifically for high temperature applications and is widely used for components in gas turbines. The alloy is typically processed by casting technologies and features an equiaxed grain structure. Due to its chemistry and thermo-physical properties, IN 738LC shows a high susceptibility to cracking during thermal processing as is the case in SLM.

Processing of IN 738LC is investigated in two preheating temperature ranges, based on two different aims:

(1) Room temperature to approx. 500 °C, in order to manufacture functional prototypes for rig-tests with out necessarily totally crack free microstructure.

- Components like a nozzle guide vane from a helicopter engine can be manufactured with a nearly crack free microstructure suitable for rig-tests. After conventional heat treatment, the microstructure shows the typical bimodal gamma-prime distribution, but with significantly smaller grains in comparison to cast parts.

(2) Above 500 °C, in order to determine minimum preheating temperature and process parameters to achieve a crack free microstructure.

- Crack free parts have been manufactured at preheating temperatures of 800 °C to 900 °C. Nevertheless, the conductive preheating through the base plate, as well as microstructural changes over the build time due to activated diffusion, lead to limitations regarding build height and parts dimensions.

Process Control of LMD Wire using Resistance Measurements (HV)

Laser metal wire deposit (LMD wire) offers great cost and weight savings potential in the aerospace industry, both in new manufacturing and repair applications. In order to fully exploit this technology the deposition process must be robust and repeatable. One way of achieving this is through feedback control (see Figure 14).

University West (HV) and GKN Aerospace Engine Systems Sweden have jointly developed a new concept for controlling laser metal wire deposit geometry. Developed solution is based on measuring the resistance of the wire and the weld pool during deposition. Thanks to the resistance's dependence on distance between the tool and the deposit, it may be used for geometry scanning of the part during processing. The measurements require no added equipment into the processing chamber and can be retrofitted to equipment already in production with minimal effort. An empirical regression model is used for converting resistance to layer height information. The obtained height information is fed into an iterative learning control system previously developed for use with data provided by a laser scanner.

The new approach of instead using resistance measurements makes not only for a solution which is cheaper and more industrially feasible, all necessary measurements are made during processing and no additional time is needed to scan the deposit after each deposited layer. Based on the layer height info the iterative learning controller gradually learns the disturbance's characteristics and compensates for them by e.g. adjusting the wire feed rate. The concept has been demonstrated in production like environment with great success.

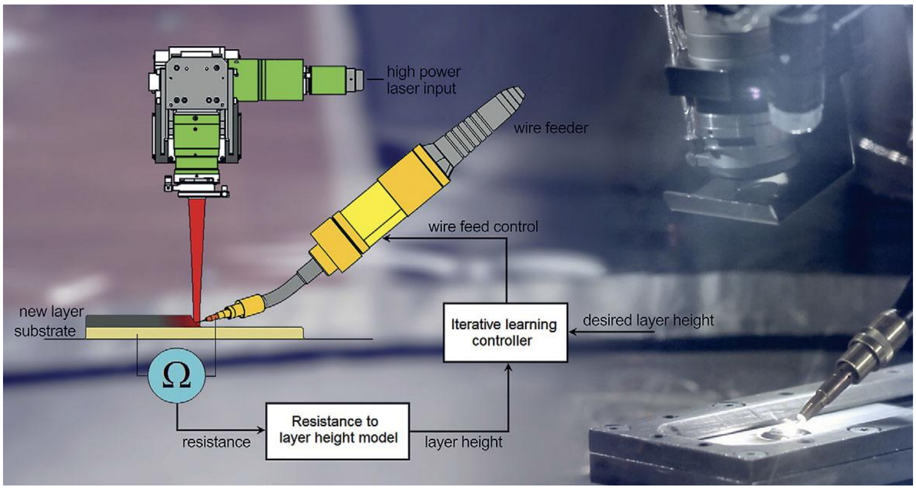


Figure 14: Process Control of LMD Wire using Resistance Measurements

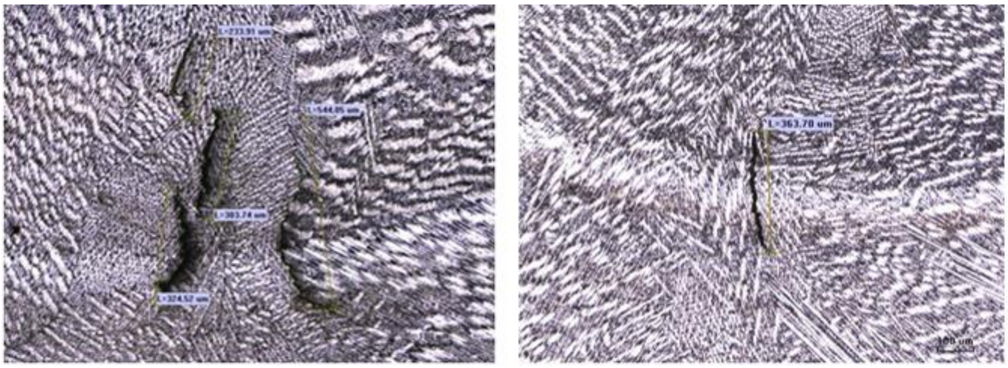


Figure 15: Left, cracks without thermal management. Right, reduced number and size of cracks after introduction of thermal management strategy (same scale).

<u>Process investigations due to thermal management with LMD-w (HV)</u>

In order to counter the crack-susceptibility of LMD-w deposited Alloy 718, a thermal management strategy was developed (see Figure 15). Early on during the project, experiments and theoretical knowledge led to the conclusion that in order to minimize cracking within LMD-w of Alloy 718, high deposition rates were preferable. Also, laser power was to be minimized in order to create narrow and high beads. Replacing laser power with wire pre-heating through hot-wire deposition proved successful in order to achieve this. The higher beads meant that fewer layers have had to be built in order to obtain the same final geometry compared to before. This, in turn, meant that the deposited material was reheated fewer times and thus exposed to less thermal cycling. When combining this high deposition rate approach with pause times after each deposited layer, in order to let the deposit cool down, proved to give much fewer cracks compared to conventional deposition. The employment of the developed thermal management strategy significantly reduced the number of cracks in the deposited Alloy 718 material, but did not guarantee crack free deposits.

Development of more complex geometries using SLM and LMD

Table 5: Main advantages, limitations and current challenges of laser additive manufacturing technologies for complex geometries

Technology	*Advantages*	*Limitations*	*Challenges*
LMD-w	• Material efficiency nearly 100 %; • High productivity; • Large parts with relative low complexity can be fabricated, limited only by handling system.	• Non-highly complex and accuracy geometries can be manufactured.	• Increase control of robotized systems; • Increase dimensional control by coupling intelligent process control;
LMD-p	• Use of non-flat bases allowed, 3D surfaces, on existing parts; • Combination with other manufacturing processes: hybrid processes (i.e. machining + LMD); • Depending on material, no controlled atmosphere is necessary; • Large parts with lower degree of complexity can be manufactured. Size limited only by handling system; • Dissimilar/multi-materials possible.	• Non-highly complex and accuracy geometries can be manufactured; • Significant powder loss in case of low material efficiency of nozzles (recycling not feasible so far).	• Increase dimensional control by coupling intelligent process control; • Thinner shapes can be built using appropriate advanced nozzles and robots/CNCs.
SLM	• High complex structures like those with channels, ducts, scaffolds and thin walls can be manufactured. Complexity nearly unlimited • Net shape components, less post processing.	• On powder (overhang features) manufacturing limits producibility; • Part size limited by the build chamber; • Large parts are difficult to be manufactured due to distortions; • Distortions in overhang areas; • Use of supports: Cannot be removed depending on the position (total or partially) and affect surface quality; • Surface quality depends on surface slope and process parameters; • Standard technology permits one material per component.	• Reduction of distortions to ensure correct final dimensions; • Apply homogeneous pre-heating of parts at approx. 700-1000 °C to avoid component distortion manufactured in IN718; • Part modelling following specific design rules to reduce supports, improve surface quality and distortions

In process geometrical control

Laser metal deposition (LMD) is an additive manufacturing technology suitable to produce parts from scratch based on a 3D model. But, LMD can do a lot more. It is also used to add material to worn out or damaged areas of high added value components e.g. components found in aero engines. A common problem of a repair task is the unpredictable geometry of the worn area. Wear is not constant and therefore each part has to be handled individually. This requires measurement and machining back worn areas of an individual parts geometry before any material adding process can be started.

To support the task BCT / ILT have integrated a laser line scanner sensor into CNC machining equipment allowing the measurement and referencing of a components worn shape directly before processing. Machine integrated measuring is beneficial because (see Figure 16):

- Parts are measured in the same position as used during subsequent processing
- No part transportation and re-referencing is required
- If used in-process then feed back to the process controller is possible

The primary challenge was synchronising the position of the laser sensor with the measured data. To improve the precision of the data capturing process, different calibration procedures were developed to compensate sensor and machine in-accuracies during measurement.

The solution developed can be used as either a standalone system e.g. to set up new repair strategies, or it can be integrated within the LMD process. This allows geometrical information to be captured which is of great importance during LMD tool path planning. Furthermore, the geometry and build up height can be captured during material addition. This technology opens up new possibilities to continuously adjust a process which is highly dependent on geometrical measurement. This will enable improved quality control during LMD processing leading to a better acceptance of the technology by potential customers.

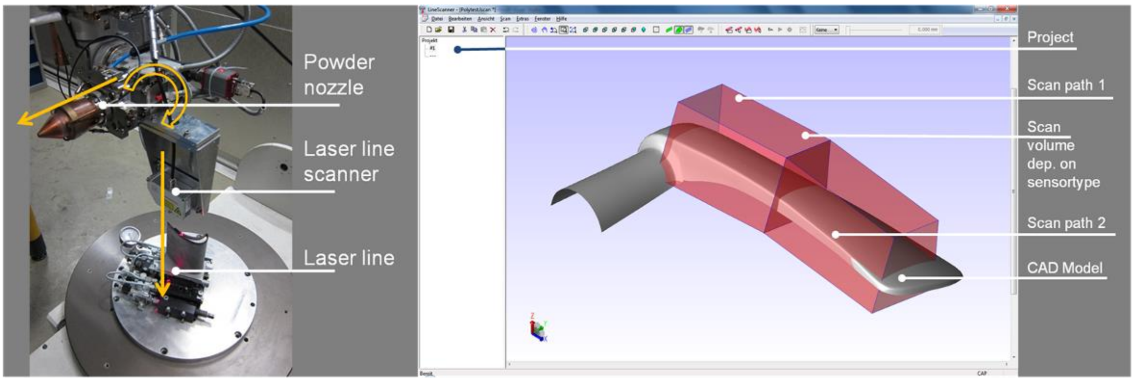


Figure 16: On the left a laser scanner mounted at the laser head inside the TRUMPF LMD machine (ILT) and on the right, User Interface laser scan software (by BCT)

1.3.5 WP4 – In-process NDT

NDT development and integration, geometrical measurement and control

Non-Destructive Testing (NDT) refers to a range of techniques for examining a structure in a non-damaging manner in order to detect and characterise flaws which might compromise its performance or safety. There are currently no commercially available NDT techniques for the in-process validation of LMD structures; most traditional inspection methods are only useful after a part has been manufactured or present obstacles to deployment for on-line inspection.

The validation activity was performed with metallographic inspection and x-ray computer tomography.

This work package was separated into two primary tasks:

- Development on an in-process LUT system for LMD (TWI and HV)
- Development on an in-process CUT system for SLM (MTU)

All four deliverables for WP4 were fully completed and submitted (D4.1 NDT System specification; D4.2 NDT system validation report ; D4.3 NDT SLM system specification and D4.4 NDT SLM validation report).

LUT NDT for LMD process

Laser Ultrasonic Testing (LUT) has been identified as the most appropriate NDT technology for the evaluation of LMD structures and integration into an LMD platform. Its advantages specific to this project can be summarised as follows:

Property of LUT	Advantage for in-process inspection of LMD-p
Non-contact – remote generation and detection of ultrasound.	Deployment on high temperature and moving surfaces is possible.
Small footprint – less than 1 mm^2 area on test surface.	Inspection of thin structures and deployment on small surfaces areas is possible.
Ultrasound is high frequency and covers a broad spectrum.	Small features such as microstructural flaws can be detected.
Surface ultrasonic waves are produced.	Surface and near-surface inspection is possible.

LUT involves the use of two laser beams. The generation of ultrasound is facilitated by a Q-switched laser beam irradiates the surface of a test sample in a short pulse, producing both surface and bulk ultrasonic waves in a thermal-mechanical interaction. The frequency of generated ultrasonic waves is broadband with energy at higher frequencies inversely proportional to the pulse duration. The detection of ultrasonic signals is facilitated by a constant wave laser beam which reflects from the area of investigation on the surface of a test sample. This laser beam stores surface displacement information due to changes in the frequency and phase of the light and is delivered to an interferometer where light signals are converted to amplitude data. One type of ultrasonic wave of particular interest in this project is the Rayleigh wave, which has both longitudinal and transverse movements and travels along the surface of the test sample with a velocity slightly slower than a shear wave. The Rayleigh wave penetrates the material to a depth equal to its wavelength, and is therefore potentially useful in detecting defects which exist at the depth of a single powder-LMD layer, which typically have a thickness of 200 µm to 300 µm

Laboratory trials of the laser LUT system were completed using thin-walled calibration samples containing side-drilled holes near to the surface to simulate defects. Continuous Laser Separation (CLS) scans were conducted in order to investigate indications generated from the simulated sub-surface flaws. Such indications were evident in both the time and frequency domains. Analysis revealed that in calibration samples with a surface finish equivalent to a deposited layer, the minimum detectable simulated flaw size was 100 µm, a diameter on the order of porosity size described in literature, although the geometry of the simulated flaws was of greater overall volume than what should be expected.

For the on-line LUT trials, a circular diameter of 300 mm was chosen for the LMD structure (Demonstrator 4). Deposition parameters were selected in order to produce a wall thickness of approximately 1.1 mm. Initially, five layers were deposited to provide a short wall structure onto which the laser beams could be directed and focused (see Figure 17). Distortion of the wall structure upon re-starting deposition was found not to be a problem at such a small height. In the first stage of LUT, surface displacement data was acquired continuously for a certain length of time while deposition took place. At a radius of 140 mm from the centre of rotation, the surface under investigation was moving at a rate of ~ 17.6 mm/s during deposition. In the second stage of LUT, surface displacement data was acquired similarly at a set of reduced rotational speeds given in Table 3. From this information, the distance by which the test surface translates between the acquisitions of successive A-scans (based on a pulse repetition rate of 20 Hz) can be calculated. HV assisted TWI with post acquisition signal processing to help gain an understanding of the LUT results.

Future work may further these investigations by finding a way to produce micro-structural flaws, or realistic equivalent volumes, in a controlled manner. In on-line trials, a laser UT system was successfully integrated into an LMD system for in-process generation and detection of surface ultrasonic waves on a thin-walled structure with circular geometry. This integrated system included remote control of laser position parameters to meet the safety requirements. It was found that the main limiting factor in the acquisition of wave data of sufficient quality for the detection of real flaws was the rate of surface motion, due to the type of two-wave-mixing interferometer used. Indications of ultrasonic wave interaction with possible flaws were not evident in the acquired data.

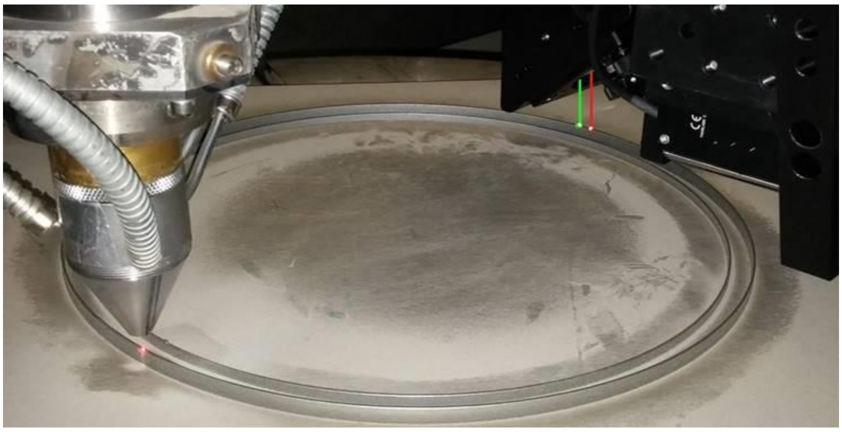


Figure 17: Relative positions of the LMD nozzle and LUT aperture on a circular wall deposit.

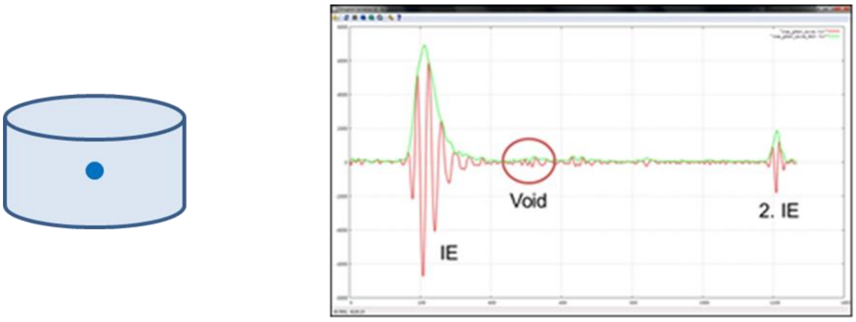
<u>CUT NDT for SLM process (MTU)</u>

The validation was based on conventional ultrasonic measurements in a modified EOS M280 SLM machine (see Figure 18). The local resolution during build-up of SLM parts was investigated as well as the detectability of synthetic internal flaws and process parameter variations.

Figure 18: New designed sensing platform (on the right: mounted platform in the EOS M280 machine)

The aim of the study was to assess detectability of internal flaws. Therefore, a cylinder with an internal void in the centre was produced by the SLM process (see Figure 19a). The cylinder consists of 250 layers, has a height of 10 mm, a diameter of 20 mm and a powder filled void with 2 mm in diameter in the centre. Unfortunately, the defect wasn't seen in the real-time A-scans. Geometry of the defect and the unfocussed sound field have not produced a good echo. Nevertheless, when averaging all A-scans captured during build-up, one gets the so-called A*-scan presentation: all changing signals over time (e.g. the back wall echo) interfere destructively and cancel each other out. In this averaged A*-scan the defect in the centre of the cylinder becomes at least a little more visible (see Figure 19b).

Today the platform integrated ultrasonic monitoring system is restricted to basic geometries of SLM parts. This is sufficient for the development of optimum SLM process parameters. In the near future the used single element transducer technique could be replaced by a phased array technique then offering the monitoring of SLM parts with more complex geometries.



(a) (b)

Figure 19: (a) Schematic presentation of a part with internal flaw and (b) A*-scan: A powerful tool of ultrasonic online monitoring.

1.3.6 WP5 - Post Processing

Mechanical testing, analysis, recycling validation and heat treatment

This work package was separated into four primary tasks:

- Task 5.1: Metallurgical Quality (RR, WSK, ITP, MTU, LPW, TM, GKN,TWI, ILT, ARMINES, Lortek, HV)
- Task 5.2: Mechanical Testing (RR, WSK, ITP, MTU, LPW, TM, GKN,TWI, ILT, ARMINES, Lortek, HV)
- Task 5.3: Validation of Recycling (Lortek and LPW)
- Task 5.4: Material Input control Specification (LPW)

All three deliverables for WP5 were fully completed and submitted (D5.1 Recycling methodology report; D5.2 Recycling analysis and testing report and D5.3 Materials properties report).

Metallurgical Quality and Mechanical Testing

Metallurgical quality and mechanical properties of built deposits have been investigated with emphasis on demonstrator parts. The effect of recycling of excessive powder has also been investigated. The beneficiaries have used their own routines for testing in order to obtain results useful for their continued development, and they have shared results on a level that does not infringe any IPR issues. The process development has been performed in WP3 prior to and/or in parallel with the testing. The three processes and materials were:

- Process SLM with materials MAR-M-247LC, Inconel 625, Inconel 718, Inconel 738
- Process LMD-p with material Inconel 718
- Process LMD-w with material Inconel 718

Metallurgical quality was mainly investigated through various micrograph analyses of the microscopic grain structure of the deposits and for finding voids like pores and cracks. Mechanical properties of the deposits have been investigated by various means, e.g. tensile testing, low-cycle fatigue and high-cycle fatigue with the aim to understand the mechanical properties of the developed processes.

Experience gained during the testing and after analysing the results will be beneficial for the continued work at the partners. Powder recycling analysis and handling has been in focus, since the amount of excessive powder in some situations is large, and it is of great environmental interest to understand how to reuse this powder while maintaining desired properties. By doing proper sieving and drying of the powder before next iteration of building, Inconel 718 powder showed to recover its initial properties even after 14 iterations, both metallurgically and mechanically.

The task has a consortium wide dissemination level. However, Table 6 and Table 7 give an indication to the types of metallurgical quality and testing required sort in the MERLIN project.

Table 6: List of materials, processes and components for Task 5.1

Specification	RR	WSK	ITP	TM	GKN/HV	Fraun-hofer	Armines
Process	SLM	LMD-w LMD-p	LMD-p SLM	SLM	LMD-w LMD-p	SLM	
Material	CM247 LC	Alloy718	Alloy718	Alloy625 Alloy738	Alloy718	IN718 IN738LC René 142/N5	
Component		Turbine support case	Vanes + inner casing	Blade shielding case (625) NGV (738)	Hot structural casing	NGV specimens	NGV
Type of indication for testing		Cracks, pores, binding defects, micro-structure	Cracks, pores, binding defects, micro-structure	Cracks, pores <50um	Cracks, pores, binding defects	Cracks, pores, binding defects	Microstructure, metallurgy, geometry, roughness

Table 7: List of materials, testing method and components for Task 5.2

Partner	WSK	ITP	MTU	TM	GKN/HV	TWI	ARMINES
Task 5.2.2 Mechanical testing of LMD-w							
Material	In718	In718					
Mechanical testing	Tensile, creep test	Tensile, LCF					
Manufacturing of material for mechanical testing		Lortek					
Correlation to demonstrator		Demo 7 - Top core vane					
Task 5.2.3 Mechanical testing of LMD-p							
Material	In718	In718 CM247LC	IN718 on LEK94		In718	Powder In718 Substrate; In718 (recycling)	
Mechanical testing	Tensile, creep test	Tensile, HCF, creep	Creep		Tensile, LCF, Crack prop	Tensile	
Manufacturing of material for mechanical testing		IN718: Lortek CM247LC: Material Solutions	ILT		TWI Heat treat GKN	TWI will manufacture as instructed by GKN. Heat Treat by GKN	
Correlation to demonstrator		Demo 9 – Diffuser Inner case (IN718) Demo 13 – Turbine nozzle guide vane (CM247LC)	Demo 6		GKN demo	GKN/TM demo	

<u>Validation of Recycling</u>

One of the most important advantages of selective laser melting process is that it allows theoretically 100 % material utilization through non-consumed powder material recycling. Nevertheless, this has been carried out in research environments with little knowledge of how the powder is affected and whether recycling the powder induces quality issues in future deposits. In production however, recycling is not always carried out, given that it is viewed as a risk, because it has not been properly validated in the procedure development phases. This is particularly important for aerospace industry, where process validation and standardization is mandatory.

MERLIN has addressed this issue for Inconel 718, one of the most widely used nickel superalloy in high temperature applications, up to 650 ºC. First, a detailed recycling methodology was defined (see Figure 20), which was further tested and validated through experimental tests, reusing recycled powder up to 14 times (LORTEK, LPW).

The methodology performed has allowed the consortium to conclude that, when applying it, the powder condition of Inconel 718 does not significantly change during its reutilization: The majority of particles remained spherical and there was no increase in defects such as craters and satellites. Particle size distribution after several production cycles was similar, with the exception of a small amount of particle aggregates that were detected with sizes between 50 and 100 microns (see SEM images below). Moreover, material composition remained also unchanged. As a consequence, test samples showed similar properties after 14 iterations, both metallurgically (in terms of equivalent microstructure and porosity) and mechanically (in terms of similar toughness). SEM images of powder: (left) before and (right) after 14 iterations sieving and drying

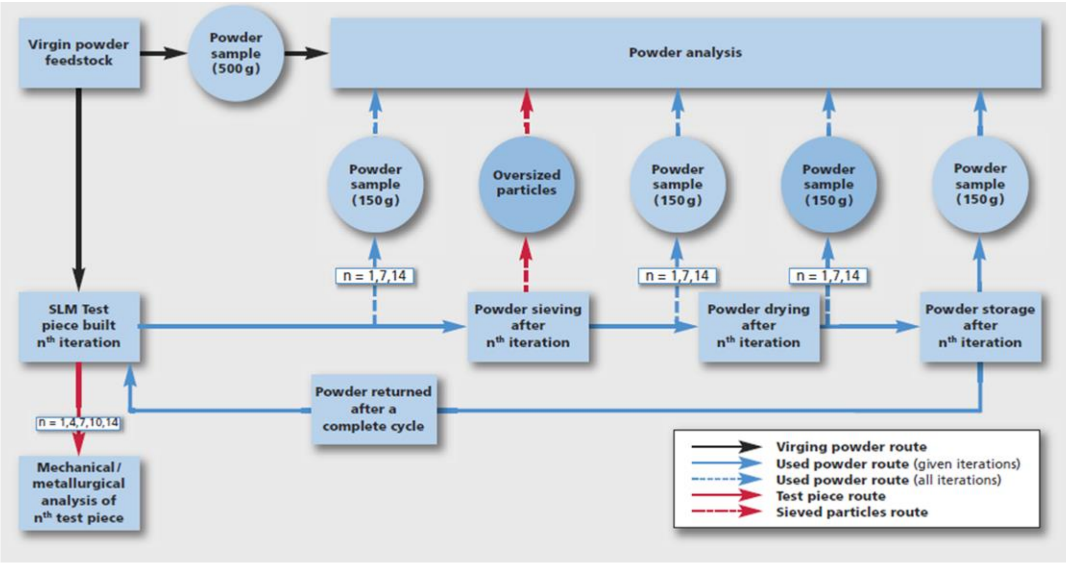


Figure 20: MERLIN powder recycling methodology.

Material Input control Specification

This task was the responsibility of LPW and involved the management of powder quality control procedures when supplying powder materials to partners in the MERLIN project. There was no specific output or deliverable from this task. Instead the task was one of continuous management and recording of powder throughput and usage.

1.3.7 Achievements of Project Objectives

The MERLIN project focussed on eight key objectives. The project achieved these objectives with the following technological achievements:

- **Productivity increase:** Improve the environmental case for additive layered manufacturing by achieving a step change improvement in productivity of the LMD and SLM process; Target: 50cm^3/hr for Inconel alloys in SLM and 10kg/hr for Inconel alloys in LMD.
    - This was achieved by SLM skin and core scanning strategy (ILT) with a theoretical build rate of 15 mm^3/s (55cm^3/hr).

- For LMD productivity targets of up to 10kg/h for both LMD-p and LMD-w was not achieved because demonstrator geometries, resolution, surface finish or substrate thickness were not suitable for high deposition rates processing (see MERLIN DR 3.1). Nevertheless, overall productivity of CAD to part using LMD over conventional manufacturing showed considerable improvement i.e. Virole demonstrator 4 where CAD to part manufacture was measurably reduced from 10 months to 1 month (see Table 3).

- **Design or Topology optimisation.** Design optimisation for light-weighting and performance benefits; Develop software capable of topology optimisation strategies including methodologies that will reduce part weight by up to 25%.
  - This was achieved by topology optimisation of the Blade shielding case where part weight, whist maintaining strength was reduced by 32%.
- **Powder recycling validation.** Validate the use of recycling, through the testing of material created using recycled powder, with a maximum of a 3% drop off in properties
  - This was achieved by LPW and Lortek who showed powder could be recycled up to 14 times before it begins to show material degradation in the final AM component.
- **In-process NDT development.** Develop an in-process Non-Destructive Testing (NDT) system, capable of detecting 200 micron pores in 500 micron thick deposits, for the Laser Metal (LMD) Process, to ensure deposited component quality. This will allow standards to be drafted that will allow the use of LMD in advanced production applications
  - This was achieved with the development of two inline NDT systems (LUT and CUT) by TWI and MTU.
- **In-process geometrical validation.** Develop a closed loop process for geometrically controlled LMD processing and evaluate the potential read across for SLM
  - This was achieved by BCT and ILT with the successful integration of a line scanner with LMD equipment to improve build quality and surface finish and increased deposition speed.
  - TWI and FRC also successfully modelled (as a first iteration) the heat distortion experience by the TM combustion casing demonstration (Demonstrator #4). This data was successfully implemented into a CAM style tool path generator to assist with maintaining the LMD powder-gas-beam-focus on top of a 0.8mm thick wall for over three hours of deposition.
- **High specification materials process development.** Improve the state-of-the-art in the LMD and SLM processes by depositing highly crack susceptible, high temperature performance alloys, such as TiAl, Mar-M-247 and Inconel, through the use of highly sensitive process monitoring and control, and advanced thermal management systems
  - This was achieved through demonstration activity for several MERLIN demonstrators with material requirements including CM247LC (RR) and René 142 on René N5 (ILT and MTU)
- **Product life cycle assessment.** Carry out a study into the benefits of using AM through the part lifecycle with respect to the amount of toxic chemicals, water and other consumables
  - This was achieved by ARMINES who concluded that AM processing in itself is not particularly resource efficient (AM machines and powder production by atomisation). However, the loss of 'wall plug efficiency' over other processes such as casting becomes insignificant when design optimisation can have significant in service benefits.
- **Technology Demonstration.** Provide at least three technology demonstrators that highlight the advantages of AM techniques, i.e. light-weighting, advanced geometries and high performance alloys
  - This was achieved by all partners through the development and manufacture of 10 demonstrators identified by MERLIN end users (see Tables 2 and 3).

1.4 Potential Impact

The MERLIN project has demonstrated that laser based additive manufacturing technologies can offer distinct advantages and solutions for the manufacture of components for civil aero engines along with reduction of cycle time as a standard requirement.

Impacts will include the development of high value, disruptive AM technologies capable of step changes in performance of aero engine component manufacture which will safeguard EU companies in the high value aero engine manufacturing field. AM will significantly reduce waste, this waste improvement will come from a large reduction in the required amounts of raw material usage as parts will be additively produced at near net shape with nearly 100% material utilisation.

The results of this project will contribute to the emerging industrial applications of AM in aerospace in Europe. The MERLIN end users have confirmed their interest and have already started looking for new applications for further study on materials and processing methods.

At the final review meeting the consortium made an assessment of the Technical highlights from the project in the form of a series of posters. These posters were then put together into a glossy brochure for public dissemination. This was to assess the overall achievements of the project, these will attribute to the impact of the project to the consortium members.

- Selective Laser Melting (SLM) – Productivity Improvement for CM247LC
- Thermo-mechanical Model of AM and Shape Accuracy Simulation
- SLM Process Development for René 142 on René N5
- Extension of Blade Root out of LEK94 with Inconel 718 by LMD-p
- SLM Process Development for Aero Engine Components in IN 738LC
- High Power SLM with Inconel 718 for Aero Engine Components
- Mechanical Testing, Analysis and Recycling Validation
- Powder: Recycle and Reuse for High Material Use Efficiency.
- In-Line Laser Ultrasonic Testing with Laser Metal Deposition
- Platform Integrated Ultrasonic Online Monitoring
- Process Control of LMD Wire using Resistance Measurements
- Metastability Induced by SLM in Nickel Based Superalloys (Inconel 738 Case)
- In-line Geometrical control of the LMD process
- Software development for CAM style automated LMD tool path development

The project results have helped to widen the range of materials and geometries that can be used/processed by Additive Manufacturing and has given a greater understanding and appreciation for the important of quality control and reproducibility of powder.

The project results have helped to widen the range of materials and geometries that can be used/processed by Additive Manufacturing and has given a greater understanding and appreciation for the importance of quality control and reproducibility of powder. It is obvious that the OEM contribution to the project is focussed on real parts and technologies to be used for design and manufacturing of aero engine parts. The OEMs plan to use the advanced knowledge to re-design components so that the new AM technologies could be used most efficiently. It is not reasonable to displace common manufacturing technologies by AM procedures without using the new design freedom offered by the use of this technology.

Because aero engines place great demands on reliability and robustness. This means that parts produced by the AM technologies have to be directly compared to the ones conventionally produced – this will form the majority of post MERLIN activity, particularly by the end users. In particular:

Beneficiary 1 RR

- Involvement in the MERLIN project enhanced a good team to develop new technology and processing of complex alloys by SLM (CM247LC).
- It was also a great benefit to experience the similar technological studies, developments in the European aerospace partners.
- The good collaboration between the partners resulted in a high productive, efficient 4-year period and also forward planning.
- IN-line LUT system developed by TWI is of great interest in other areas of the company and RR will work with TWI to investigate other technologies that might benefit from LUT inspection.

Beneficiary 2 WSK

- Improved understanding and the requirements of closed loop feedback control during LMD-w processing.
- Topology optimisation of bosses on engine casings has given an increased understanding of loosening manufacturing restraints on engine casing design when focused on AM technologies.

Beneficiary 3 IPT

- Further development of LAM technologies for ITP.
- Greater understanding over the requirements for powder characterisation and recyling

Beneficiary 4 MTU

MTU is gaining knowledge in the field of life cycle analysis and acceptance and inspection criteria especially for HPC and LPT products like honeycombs. This knowledge should be incorporated in the production of the next generation geared turbo Fan (GTF) engine family, which should be used for A320neo and Bombardier C-Series. So, the MERLIN results are intended to be used in commercial products at the end of the project. Further interests also include:

- Increased understanding of Selective Laser Melting of a non-weldable Ni- Base Superalloy on a Single Crystal Ni-Base Superalloy.

Beneficiary 5 LPW

LPW as the SME focussed on the powder delivery and powder usage will integrate these new experiences in their product portfolio for powder and wire applications. In particular:

- Use of gained knowhow to promote capability for powder optimisation, quality and reproducibility.
- The use and handling of new materials and new powders.
- Increased expertise on the supply of powders for aerospace applications (requirements).
- Several new employees hired during the project to remain with the company to assist with the implementation of results.
- The project will benefit the company in taking forward and offering further assistance in the development of materials and materials characterisation.
- Increased understanding of the effects of recycled powder reuse on properties of parts manufactured by Selective Laser Melting

Beneficiary 6 TM

- Increased our know-how on laser sintering system and CAD-CAM tools for geometries produced by LMD.
- New products (Virole demonstrator) to be investigated further with test bed engine trials.

Beneficiary 7 GKN

GKN is interested in gaining deeper knowledge concerning the LMD procedures for aerospace materials. Possible applications in GKN are high temperature and high strength applications. Together with HV, GKN is working on the LMD-wire based approach allowing high deposition rates. The experiences of MERLIN should be used for GKN typical applications at the end of the project. Of further particular interest:

- Are the productivity results comparing LMD-p and LMD-w alongside each technologies capability for depositing material onto thin substrate (engine casings).
-

Beneficiary 8 TWI

TWI is working on different tasks. NDT technologies are being examined post MERLIN (together with HV) to see if they could be used inside new technologies and applications. TWI are also planning to continue the work of MERLIN to fully integrate the NDT equipment to give additional capability for in-process inspection. TWI will also gain knowledge concerning the LMD procedures which will support all further activities in the area of manufacturing complex shaped parts for aero engines, power generation or even automotive. Knowledge in this context means process and material know how. Other interests and activities ignited by merlin include:

- TWI has benefitted from the development of new processing parameters for Laser AM techniques and new powder compositions (LMD processing of finer powders (20-40 micron size range for parts with high geometrical accuracy)
- Development of TWI technology capability for industrial applications including the Virole demonstrator.
- Development of LMD CAD software for automatic toolpath generation. The software in MERLIN have proven to be an excellent tool for fast turn-around of multi-layer tool paths for more efficient experimentation. Further, the Virole demonstrator would not of been easily manufactured, if not impossible, using existing commercial LMD software. Release a cut down free licence software package for beta testing (2016)

Beneficiary 9 ILT

ILT as an institute specialised in laser applications. Their expertise is used inside MERLIN to gain some fundamental knowledge about the processing of high temperature alloys e.g. IN738LC to be used in gas turbines. Another central task is the development and the examination of the so-called skin-core technology. First results are promising and will lead to significant shorter process times by an improved surface quality. Typical for the research institutes ILT is not planning the use these knowledge for commercial application. But, of course the knowledge could be transferred at the end of the project to other applications. In particular:

- The developed technologies will strengthen the activities of ILT in the field of Laser Additive Manufacturing Processes. The technical expertise can be adapted to other areas in laser material processing.
- Another benefit is the European network of SMEs, companies and research organizations.
- Identified and testing real applications for high productivity SLM through skin and core scanning strategies
- Developed new capability for processing complex alloys by SLM (René 142 on René N5.)
- Influence of process management on crack formation in nickel-based alloy parts (IN 738LC) manufactured by SLM
- Numerical Computation of Component Shape Distortion Manufactured by Selective Laser Melting.

Beneficiary 10 ARMINES

ARMINES is working on the topology of new part design. Changing the manufacturing method should be reflected in the part design supported by TM. If design and technology are harmonised, maximum benefit can be realised. This should be proofed by producing a number of demonstrator parts TM post MERLIN project. In particular:

- Study of the departure from equilibrium and of the thermal behaviour of Ni-based superalloy powders and dense materials manufactured by selective laser melting

Beneficiary 11 LORTEK

- Increased understanding of the effects of recycled powder reuse on properties of parts manufactured by Selective Laser Melting

Beneficiary 12 BCT

BCT, as the other SME working in MERLIN, focused on the adjustment of process paths to avoid geometrical deviations. This is based on measuring and predicting distortions and path corrections as a result of modelling algorithms to adjust the cladding part (if necessary). This new approach should constitute another application module for BCTs Advanced repair and manufacturing software. It is planned to commercialise this module at the end of the project. Other areas of interest for BCT include:

- Working on new technologies with big market potential.
- International collaboration between SMEs, researches and industry.
- Gaining deeper knowledge of AM processes.
- Development of inline geometrical control system for future exploitation in LMD markets.

Beneficiary 13 HV

HV is concentrating on temperature measurement during the IN 718 deposition process by LMD-w. This should allow a better understanding of the process and should help to improve the technology. HV and GKN plan to further develop results and understanding gained in MERLIN. In particular:

- Emissivity compensated spectral pyrometry for varying emissivity metallic measures for LMD-w
- Emissivity compensated spectral pyrometry-algorithm and sensitivity analysis
- NDT LUT developments and post-acquisition signal processing i.e. Sizing of subsurface defects in thin walls using laser ultrasonics
- Increased understanding of resistance based iterative learning control of additive manufacturing with wire

Beneficiary 14 FRC

FRC will develop algorithms allowing the predicting of geometrical inaccuracies which can be used as an input for the adjustment procedure for a wide range of applications in AM. In particular:

- A thermo-mechanical modelling reduction approach for calculating shape distortion in SLM manufacturing for aero engine components
- Computational Reduction Model for Appraising Structural Effects in Selective Laser Melting Manufacturing
- Numerical Computation of Component Shape Distortion Manufactured by Selective Laser Melting.

1.5 Project Website

Since the start of the project, MERLIN has had a dedicated website, www.merlin-project.eu to present the MERLIN project to the public (see Figure 21). This has been, and will continue to be, crucial to the dissemination activities of the project. Internet is today the sole most efficient media of communication and thus it is our single most important dedicated disseminating tool.

The site features two main goals: it functions as a source of information for the broader community of users and also as a vault of specific project information available only for the project partners.

It is used not only to explain and promote the technology, either using general information or more detailed case studies information, but also to link the project to the partner’s community and other interesting sites and projects.

The project website is maintained by TWI the Project Coordinator and can be accessed through the details on the front of this report.

Figure 21: The MERLIN project website (www.merlin-project.eu)

The Members Area of the website (see Figure 22) is designed to store and exchange documents and information between the partners. The live document, 'PUDF' is located on this central location so that all partners are able to enter new publications, events etc. directly.

- Lessons learned: Central maintenance of the folders related to dissemination by the dissemination manager is beneficial. Access conflicts can be avoided and central management allows a better monitoring.
- Lessons learned: The storage capacity should be assessed at the beginning of the project. Hereby technical information, size of pictures or even videos should be taken into account.
- Lessons learned: Urge partners to minimise the document size to support information exchange and to avoid typical e-mail restrictions.

This section of the web site is used by all MERLIN beneficiaries and all relevant documents can be found here. During the last year of MERLIN the website was extended by adding a specific ftp section to store big files and videos or deliverables.

- Lessons learned: Easy access to the partner area is the fundamental requirement for acceptance of this tool inside the consortium.
- Lessons learned: Structure should not be too complex to allow handling by time to time users.

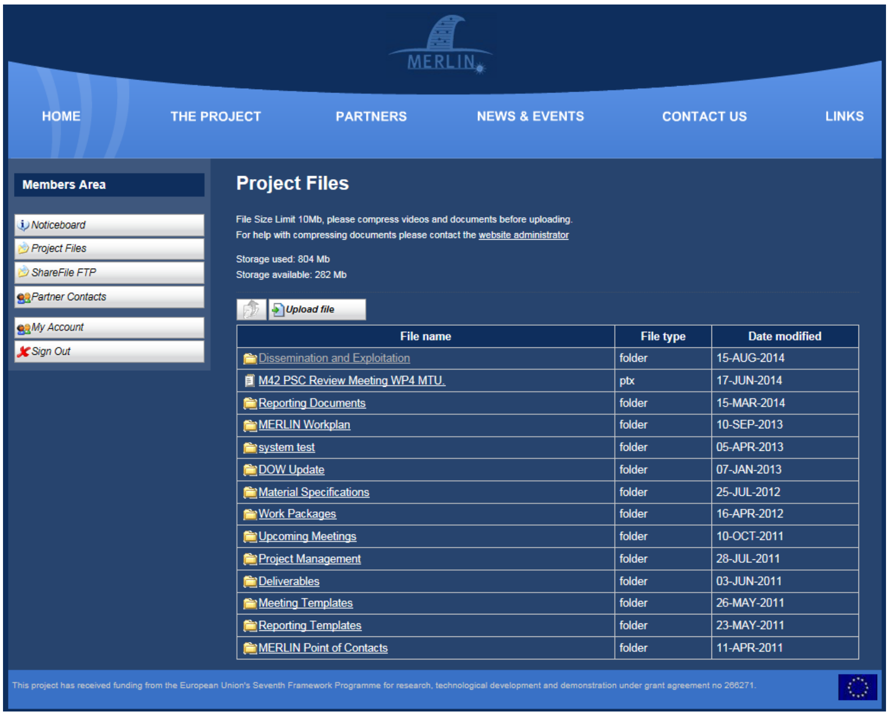


Figure 22: The MERLIN project website (Members area)

2. Plan for use and Dissemination of Foreground (PUDF)

Although research projects like MERLIN are mainly focused on technical developments, it is also part of the work to present the results to a wider public e.g. on conferences or in the daily business of education at universities and schools. Interest should be aroused in industry as well in the educational area to get young academics working on these interesting and important new technologies in future.

In combination with disseminating the results – if not classified as confidential – a convincing plan has to be presented showing that research work is not done for the sake of itself. All research work co-financed by the European Union and the European tax payers should lead to results to be used within European industries directly or later on. The research should therefore lead to a better knowledge of processes and technologies in Europe.

To fulfil the above mentioned objective a first version of the Plan for Use and Dissemination of Foreground (PUDF) was presented in M14. *Foreground* in this context summarises all the project results achieved during the MERLIN project work. The final version of the PUDF (Deliverable D8.3) gives an overview about the dissemination activities and the exploitable results of the MERLIN project.

MERLIN is a level 1 project (see Figure 23) concentrating on breakthrough research to improve AM technologies for the manufacture of aero engine components. The focus was on the development of critical technologies like powder and wire LMD as well as SLM and on other challenging details of such technology developments. Improving simulation methods, integrating NDT capabilities as well as introducing geometrical measuring capabilities were intended to support the above mentioned developments.

It is in the nature of a level 1 project which is in-between fundamental and applied research, that most of the achievements made in the project cannot be used directly in industrial applications without further developments and further improvements. Especially if the parts produced by additive manufacturing technologies should be used in aero engines, numerous tests have to be made and required approvals have to be obtained.

Due to this, it is not the expectation of the MERLIN consortium that the project developments result in a 'MERLIN process' or a 'MERLIN system' to be offered on the market at the end of the project, directly. But, of course it will be shown that the fundamental research work is suitable to pave the way for the emerging additive manufacturing procedures. The results of MERLIN have to be seen as small components of the bigger picture of additive manufacturing of complex parts allowing the use of this technology even for the most complex and challenging tasks in aero engine manufacture.

Based on the background that aero engine applications are the most demanding applications for AM, the requirement specifications are extremely challenging. Improving the production of the parts while not compromising the quality is a big issue.

To prove the applicability of the new technological developments a set of demonstrator objects was designed and specified by the OEMs which will be manufactured and tested to prove the capabilities or to show the limitations of such processes (WP6).

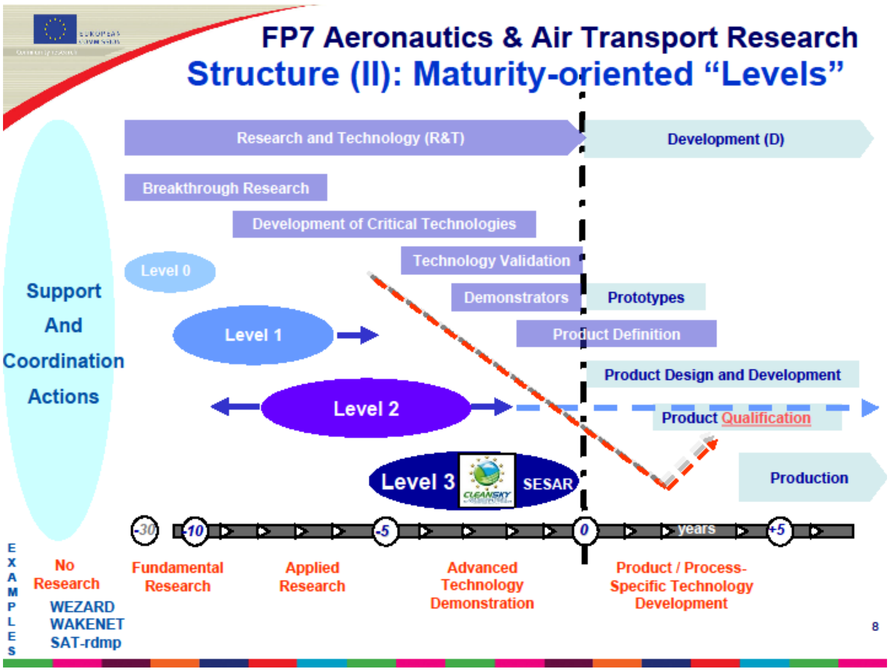


Figure 23: (European Union Framework Programme FP7 Aeronautics & Air Transport, Safety and Research policy, by Pablo Perez-Illana).

2.1 Key Exploitable results

This section provides detailed information about the key exploitable results of MERLIN and is therefore one of the most important sections of the PUDF. The information was provided by the partners involved in the research work leading to the results and monitored on a regular basis. The table reflect the status at the end of the project.

Exploitable Result No.	Key exploitable result	Lead Partner	Foreground IPR
1	In Process NDT	TWI Wales	Knowledge about using LUT in LMD processes. Experiences in mounting LUT equipment to a LMD machine. Monitoring based on reference signals. LUT signal analysis in cooperation with HV.
2	LMD procedure development for complex geometries and aerospace materials	TWI, GKN, HV, ITP, ILT	Process knowledge focused on the production of complex geometries like blades or nozzle guide vanes used in aero engines in combination with processing high temperature resistant alloys
3	SLM Fundamental knowledge about processing of high temperature alloys	ILT	Process knowledge to manufacture crack and pore free parts of high temperature alloys
4	HP-SLM Fundamental knowledge about processing of materials	ILT	Experiences in high power selective laser meting processes. Power distribution, preheating and processing strategies
5	Knowledge on: "When to use what method" for additive manufacturing	ALL	
6	Equipment design and specification for Additive Manufacturing LMD-w	HV, GKN	Knowledge in additive manufacturing using wire LMD-w.
7	Modelling software	FRC, ARMINES	Algorithms and settings for predicting geometrical inaccuracies of complete structures. Calculation methods to evaluate temperature gradients and high

Exploitable Result No.	Key exploitable result	Lead Partner	Foreground IPR
			stress formation during the SLM or LMD Processing. Methods to simplify the calculation and tools for modelling thermal and thermo-mechanical effect on whole AM components.
8	Temperature measurement during IN718 deposition	HV; GKN	Knowledge about temperature measuring systems for this special application which may lead to an industrial solution after spending some more effort.
9	Scanning technologies for in process geometrical control	BCT	Experiences and software modules required to use of the shelf laser line scanning sensor inside LMD machining equipment. Calibration routines and data handling tools to represent the part in a unique coordinate system.
10	Online non-destructive testing methods for control of potential defects (e.g. pores)	MTU	Integration of non contact, non destructive sensors supporting the quality control during the build up process in SLM processing chambers. Patent may be possible.
11	Tool path generation based on in process geometrical measurements	BCT, ILT	Algorithms to adjust LMD tool paths based on geometrical measuring results.
12	Selective Laser Melting manufactured NGV	TM	Process knowledge, processing complex parts with SLM technology.
13	LMD manufactured Combustion Chamber with reduced number of parts	TM	Process knowledge, processing complex parts with thin walls using LMD technology in combination with a 5axis machine kinematics.
14	Boss on Plate	RR	Knowledge about adding additional features to base parts like thin metal sheets. This hybrid approach could lead to shorter manufacturing times and allows to test several options during the design and test phase of aero engine developments. This approach is also suited of repair purpose.
15	CM247LC LP NGV	RR	Basic know how processing the specific material wit LMD / SLM technologies
16	Recycling, Re-Use	Lortek; LPW	Knowledge about powder recycling leading to customer advice how to handle powder to allow re-use without compromising the quality.
17	Software for LMD processing	TWI	Software module supporting the LMD path generation for rotation symmetric thin walled parts.

2.2 Section A

Some MERLIN articles have been peer reviewed before publication. They are now listed in table A1. Furthermore one PhD Thesis has been finalised including interesting findings related to MERLIN. Other PhD Thesis works are ongoing and they will be finalised after the end of MERLIN.

The consortium is still quite active presenting the MERLIN project work and some of the research results, so that we are proud to present a long list of publications and conference contributions (Table A2). Various platforms like internet, conferences and trade fairs have been used to introduce the MERLIN project to the public.

Template A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[13] (if available)	Is/Will open access[14] provided to this publication?
1	"Emissivity Estimation for High Temperature Radiation Pyrometry on Ti-6Al-4V"	HV	http://www.journals.elsevier.com/measurement/	01.02.12	Elsevier		2012			Yes
2	Resistance measurements for control of laser metal-wire deposition	HV	Optics and Lasers in Engineering	Mai 13	Optics and lasers		2013			yes
3	Emissivity compensated spectral pyrometry for varying emissivity metallic measurands	HV	Measurement Science and technology	Jan 14	Measurement Science and technology		2014			
4	Emissivity compensated spectral pyrometry - algorithm and sensitivity analysis	HV	Measurement Science and technology	Jan 14	Measurement Science and technology		2014			

Template A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[13] (if available)	Is/Will open access[14] provided to this publication?
5	Effect of IN718 Recycled Powder Reuse on Properties of Parts Manufactured by Means of Selective Laser Melting	Lortek, LPW	Lane conference, Fürth, Germany	8-11.09.2014	Physics Procedia		2014			
6	Idiosyncrasy and operating of the selective laser melting process. Application on two nickel-based superalloy and energetic account	ARMINES	PhD Thesis		ARMINES		2104			

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
					-			
			PLANNING / IDEAS	**2012**				
1	Publication	HV	Article "Emissivity Estimation for High Temperature Radiation Pyrometry on Ti-6Al-4V"	01.02.12	http://www.journals.elsevier.com/measurement/	science		international
2	Seminar	FRC	Seminar at the University of Cyprus	07.03.12	Cyprus	students	20	local
3	Conference	TWI	AKL 12 "Laser Additive Manufacturing as a key enabler for the manufacture of next generation jet engine components- technology push"	09-11. 05.2012	Aachen, Fraunhofer ILT: www.lasercongress.org/en/index.html	experts	>100	international
4	Conference	ILT	AKL 12 "Additive Manufacturing of Turbine Engine Parts by Selective Laser Melting"	09-11. 05.2012	Aachen, Fraunhofer ILT: www.lasercongress.org/en/index.html	experts	>100	international
5	Conference	RR/TWI	AKL 12 "EU Project MERLIN Needs and Demands for the Manufacture of Next Generation Jet Engine Components"	09-11. 05.2012	Aachen, Fraunhofer ILT: www.lasercongress.org/en/index.html	experts	>100	international
6	Seminar	HV	Comparison of wire- and powder deposition	01.06.12	PSC-meeting	members	20	at least within the consortium

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
7	Publication	TWI/ILT	Article about laser technology based on the AKL activities	June 2012	aerotec-online.de	science		international
8	Conference	FRC	The 2012 International Conference of Manufacturing Engineering and Engineering Management (ICMEEM)	4.-6.07.2012	London	science		international
9	Conference	TWI	International Conference on Additive manufacturing	10-11.07.2012	Loughborough University, (Nottingham)	science		international
10	Publication Platform	all	Materials Knowledge Transfer Network (KTN)		www.materialsktn.net	science/ industry	global	international
11	Link to MERLIN website	LPW	LPW Website www.lpwtechnology.com	13.07.12	LPW website	industry	global	international
12	Trade Fair	BCT, TWI	Farnborough Air show	09-13.07.12	Farnborough Air show	industry	>1000	international
13	Conference	TWI	Presentation of MERLIN Poster	Aug 12	Solid Freeform Fabrication Conference, Austin, Texas USA	Academics and industrialists	120	International

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
14	Seminar	TWI	Presentation: Tile - EU Project MERLIN - New Challenges and Perspectives for Laser Additive Manufacturing in Aerospace Applications.	Sep 12	TWI/EWI seminar, Munich Germany	Experts	>100	International
15	Conference	LPW	RM FORUM 'METAL SINTERING'	20-21.09.2012	Milan, Italy	Experts	100+	international
16	Conference	TWI	Keynote Presentation on MERLIN and AM technologies at EPMA	Sep 12	EUROPM 2012, Basel, Switzerland. 16-19th September	Academics and industrialists	approx. 200	International
17	Conference	ITP	Presentation of MERLIN activities within the conference subject: "Additive Manufacturing: The challenge is getting real"	Okt 12	ITP-Madrid	Experts/Industry	Approx 250	International (ITP Group)
18	Link to MERLIN Website or MERLIN poster from TM website		TM website (http://www.turbomeca.com/english/about-us/r-d-57/programs.html)	November 2012	TURBOMECA			
19	Description of the MERLIN project		TIM (Turbomeca Information Magazine)	November 2012	TURBOMECA			

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
20	Link to MERLIN Website or MERLIN poster from IK4 LORTEK website		IK4 LORTEK R&D activities	1. trimester 2013	IK4 LORTEK website (http://www.lortek.es/)	Public	Depend on visits to website	International
21	Trade Fare	ILT	(1) Presentation of IN738LC part based on MERLIN Demonstrator, (2) Presentation of MERLIN Demonstrator (simplified NGV from TM) manufactured by HP-SLM and skin-core strategy out of IN718, (3) Presentation of MERLIN Poster and Flyers	27.-30. Nov. 2012	EUROMOLD	Academics and industrialists	approx. 60.000	international
				2013				
22	Conference	LPW	Additive manufacturing solutions	12-13.02.2013	Laser Additive Manufacturing Workshop USA			international
23	Conferecne	LPW	Additive manufacturing solutions	12-13.03.2013	International Laser Application Symposium 2013			international

MERLIN

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
24	Publication	ILT	Influence of process management on crack formation in nickel-based alloy parts (IN738LC) manufactured by SLM	2013	Either AM or material science orientated journal	science		international
25	Conference	ILT	Influence of process management on crack formation in nickel-based alloy parts (IN738LC) manufactured by SLM	14-15.05.2013	Rapidtech, Erfurt	science		international
26	Publication	HV	Resistance measurements for control of laser metal-wire deposition	Mai 13	Optics and Lasers in Engineering	science		international
27	Publication	ILT	Processing of IN718 with HP-SLM and skin-core strategy	2013	Either AM orientated journal	science		international
28	Conference	ILT	Manufacturing of gas turbine parts by SLM/HP-SLM, current state within MERLIN	2013	International Conference on Additive Manufacturing in Loughborough	Academics and industrialists		International
29	Conference	TWI (Wales)	3rd International Symposium on Laser Ultrasonics and Advanced Sensing (LU2013)	25-28.06	Yokohama, Japan	science		international
30	Conference, Publication	FRC, ILT	A thermo-mechanical modelling reduction approach for calculating shape distortion in SLM manufacturing for aero engine components	05.07.13	9th International Conference on Advanced Research in Virtual and Rapid Prototyping (VRAP) Leira Portugal	science		international

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
31	Workshop	ILT	Selective Laser Melting of Nickel Based Superalloys - Process development towards Manufacturing of Aeronautic Components	09.11.10.2013	EASN Workshop Polytechnico Milano	science		international
32	Workshop	TWI	MERLIN Project: Development of Aero Engine Component Manufacture using Laser Additive Manufacturing; An Overview presentation	09.11.10.2013	EASN Workshop Polytechnico Milano	science		international
33	Workshop	TWI/RR	The use of Laser Metal Deposition for the manufacture of Aerospace Components	09.11.10.2013	EASN Workshop Polytechnico Milano	science		international
34	Publication	FRC	A Computational Reduction Model for Appraising Structural Effects in Selective Laser Melting Manufacturing		Virtual and Physical Prototyping	science		international
35	Publication	Lortek	Annual Report	01.12.13	Lortek Report for customers/partners			
36	Conference	TWI	Presentation of MERLIN Poster	Dec. 13	Solid Freeform Fabrication Conference, Austin, Texas USA	Academics and industrialists	120	International
				2014				
37	Publication	HV	Emissivity compensated spectral pyrometry for varying emissivity metallic measurands	Jan 14	Measurement Science and technology			

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
38	Publication	HV	Emissivity compensated spectral pyrometry - algorithm and sensitivity analysis	Jan 14	Measurement Science and technology			
39	Publication	HV,TWI	Sizing of subsurface defects in thin walls using laser ultrasonics	Apr 14	???			
40	Publication	FRC, ILT	Numerical computation of Component Shape Distortion Manufacture by Selective Laser Melting	03-04-04-2014	Manu light conference, Dortmund			
41	Poster Presentation	TM	a one-day seminar organized by our region: TechnoDay	Apr 14	Agen (France)			
42	Conference Contribution	TWI	5 Axis Laser Metal Deposition for the additive manufacture of metal parts	Aug 14	SFF conference Austin, Texas			
43	Conference & Paper	Lortek, LPW	Effect of IN718 Recycled Powder Reuse on Properties of Parts Manufactured by Means of Selective Laser Melting	8-11.09.2014	Lane conference, Fürth, Germany	Physics Procedia	Conference (100-200), Paper (open source)	international
44	Conference Contribution	TWI	'A revolution in Laser Metal Deposition'	11-12.11.2014	Advanced Engineering UK, NEC Birmingham	manu-facturing & science	100	Europe

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
45	Course module	HV&TWI	Course material for PhD-course in production engineering regarding LMD-p and LMD-w	2014	presented at PSC-meeting first time	manu-facturing & science	100	Europe
46	Results of the MERLIN project		TIM (Turbomeca Information Magazine)	November 2014	TURBOMECA			
47	paper	ILT / TM	International paper (Scripta materialia or equivalement) Evaluation of mechanical characteristics of Inconel 738 made of SLM	2014	Elsevier or others			
48	meeting		results of MERLIN / applications in TM	2014				
49	Conference	TWI	Presentation of MERLIN Poster	Dez 14	Solid Freeform Fabrication Conference, Austin, Texas USA	Academics and industrialists	120	International
50	Conference	Lortek	Various presentations	2014, December 11	LORTEK http://www.lortek.es/files/pdf-merlin-en.pdf & http://www.twi-global.com/news-events/events/dissemination-workshop-of-merlin-fp7-project/	Academics and industrialists	30-40	national (Spain)

Template A2	LIST OF DISSEMINATION ACTIVITIES							
No.	Type of activities [15]	Main leader	Title	Date	Place	Type of audience [16]	Size of audience	Countries addressed
51	Website	TWI	Presentation of the developments linked to LMD of rotation symmetric parts	Nov 14	http://www.machinery.co.uk/			International
					http://www.machinery.co.uk/machinery-news/twis-yorkshire-technology-centre-has-demonstrated-additive-manufacture/66000/			
				2015				
52	Aerospace panel	TWI	Aerospace Panel for TWI members	March 15	TWI Cambridge	manu-facturing & science	20-25	international

2.3 Section B

The rules and conditions for handling the knowledge gained during the project work are defined in the Consortium Agreement (CA) and the Grant Agreement (GA). There are no separate arrangements opposing the general rules stated in the CA and GA.

This section specifies the exploitable foreground and provide the plans for exploitation (see Table B2). This information is non-publishable (**confidential**).

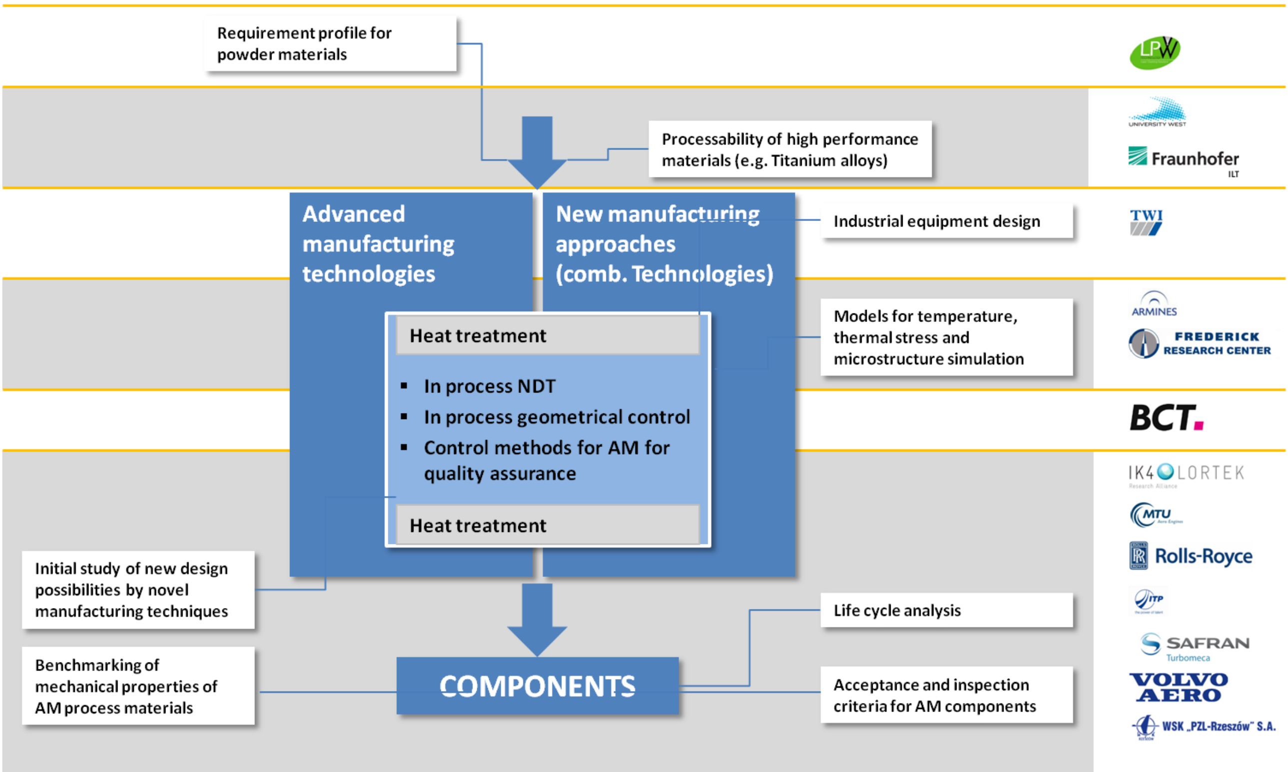


Figure 24: MERLIN Beneficiaries and exploitable foreground

Figure 24 gives a brief overview in which fields of technology and application results are expected. It is obvious that the OEM contribution to the project is focussed on real parts and technologies to be used for design and manufacturing of aero engine parts. The OEMs plan to use the advanced knowledge to re-design components so that the new AM technologies could be used most efficiently. It is not reasonable to displace common manufacturing technologies by AM procedures without using the new design freedom offered by the use of this technology.

Because aero engines place great demands on reliability and robustness. This means that parts produced by the AM technologies have to be directly compared to the ones conventionally produced – this will form the majority of post MERLIN activity, particularly by the end users. In particular:

Beneficiary 1 RR

- Involvement in the MERLIN project enhanced a good team to develop new technology and processing of complex alloys by SLM (CM247LC).
- It was also a great benefit to experience the similar technological studies, developments in the European aerospace partners.
- The good collaboration between the partners resulted in a high productive, efficient 4-year period and also forward planning.

- IN-line LUT system developed by TWI is of great interest in other areas of the company and RR will work with TWI to investigate other technologies that might benefit from LUT inspection.

Beneficiary 2 WSK
- Improved understanding and the requirements of closed loop feedback control during LMD-w processing.
- Topology optimisation of bosses on engine casings has given an increased understanding of loosening manufacturing restraints on engine casing design when focused on AM technologies.

Beneficiary 3 IPT
- Further development of LAM technologies for ITP.
- Greater understanding over the requirements for powder characterisation and recyling

Beneficiary 4 MTU
MTU is gaining knowledge in the field of life cycle analysis and acceptance and inspection criteria especially for HPC and LPT products like honeycombs. This knowledge should be incorporated in the production of the next generation geared turbo Fan (GTF) engine family, which should be used for A320neo and Bombardier C-Series. So, the MERLIN results are intended to be used in commercial products at the end of the project. Further interests also include:
- Increased understanding of Selective Laser Melting of a non-weldable Ni- Base Superalloy on a Single Crystal Ni-Base Superalloy.

Beneficiary 5 LPW
LPW as the SME focussed on the powder delivery and powder usage will integrate these new experiences in their product portfolio for powder and wire applications. In particular:
- Use of gained knowhow to promote capability for powder optimisation, quality and reproducibility.
- The use and handling of new materials and new powders.
- Increased expertise on the supply of powders for aerospace applications (requirements).
- Several new employees hired during the project to remain with the company to assist with the implementation of results.
- The project will benefit the company in taking forward and offering further assistance in the development of materials and materials characterisation.
- Increased understanding of the effects of recycled powder reuse on properties of parts manufactured by Selective Laser Melting

Beneficiary 6 TM
- Increased our know-how on laser sintering system and CAD-CAM tools for geometries produced by LMD.
- New products (Virole demonstrator) to be investigated further with test bed engine trials.

Beneficiary 7 GKN
GKN is interested in gaining deeper knowledge concerning the LMD procedures for aerospace materials. Possible applications in GKN are high temperature and high strength applications. Together with HV, GKN is working on the LMD-wire based approach allowing high deposition rates. The experiences of MERLIN should be used for GKN typical applications at the end of the project. Of further particular interest:
- Are the productivity results comparing LMD-p and LMD-w alongside each technologies capability for depositing material onto thin substrate (engine casings.

Beneficiary 8 TWI
TWI is working on different tasks. NDT technologies are being examined post MERLIN (together with HV) to see if they could be used inside new technologies and applications. TWI are also planning to continue the work of MERLIN to fully integrate the NDT equipment to give additional capability for in-process inspection. TWI will also gain knowledge concerning the LMD procedures which will support all further activities in the area of manufacturing complex shaped parts for aero engines, power generation or even automotive.

Knowledge in this context means process and material know how. Other interests and activities ignited by merlin include:

- TWI has benefitted from the development of new processing parameters for Laser AM techniques and new powder compositions (LMD processing of finer powders (20-40 micron size range for parts with high geometrical accuracy)
- Development of TWI technology capability for industrial applications including the Virole demonstrator.
- Development of LMD CAD software for automatic toolpath generation. The software in MERLIN have proven to be an excellent tool for fast turn-around of multi-layer tool paths for more efficient experimentation. Further, the Virole demonstrator would not of been easily manufactured, if not impossible, using existing commercial LMD software. Release a cut down free licence software package for beta testing (2016)

Beneficiary 9 ILT

ILT as an institute specialised in laser applications. Their expertise is used inside MERLIN to gain some fundamental knowledge about the processing of high temperature alloys e.g. IN738LC to be used in gas turbines. Another central task is the development and the examination of the so-called skin-core technology. First results are promising and will lead to significant shorter process times by an improved surface quality. Typical for the research institutes ILT is not planning the use these knowledge for commercial application. But, of course the knowledge could be transferred at the end of the project to other applications. In particular:

- The developed technologies will strengthen the activities of ILT in the field of Laser Additive Manufacturing Processes. The technical expertise can be adapted to other areas in laser material processing.
- Another benefit is the European network of SMEs, companies and research organizations.
- Identified and testing real applications for high productivity SLM through skin and core scanning strategies
- Developed new capability for processing complex alloys by SLM (René 142 on René N5.)
- Influence of process management on crack formation in nickel-based alloy parts (IN 738LC) manufactured by SLM
- Numerical Computation of Component Shape Distortion Manufactured by Selective Laser Melting.

Beneficiary 10 ARMINES

ARMINES is working on the topology of new part design. Changing the manufacturing method should be reflected in the part design supported by TM. If design and technology are harmonised, maximum benefit can be realised. This should be proofed by producing a number of demonstrator parts TM post MERLIN project. In particular:

- Study of the departure from equilibrium and of the thermal behaviour of Ni-based superalloy powders and dense materials manufactured by selective laser melting

Beneficiary 11 LORTEK

- Increased understanding of the effects of recycled powder reuse on properties of parts manufactured by Selective Laser Melting

Beneficiary 12 BCT

BCT, as the other SME working in MERLIN, focused on the adjustment of process paths to avoid geometrical deviations. This is based on measuring and predicting distortions and path corrections as a result of modelling algorithms to adjust the cladding part (if necessary). This new approach should constitute another application module for BCTs Advanced repair and manufacturing software. It is planned to commercialise this module at the end of the project. Other areas of interest for BCT include:

- Working on new technologies with big market potential.
- International collaboration between SMEs, researches and industry.
- Gaining deeper knowledge of AM processes.
- Development of inline geometrical control system for future exploitation in LMD markets.

Beneficiary 13 HV

HV is concentrating on temperature measurement during the IN 718 deposition process by LMD-w. This should allow a better understanding of the process and should help to improve the technology. HV and GKN plan to further develop results and understanding gained in MERLIN. In particular:

- Emissivity compensated spectral pyrometry for varying emissivity metallic measures for LMD-w
- Emissivity compensated spectral pyrometry-algorithm and sensitivity analysis
- NDT LUT developments and post-acquisition signal processing i.e. Sizing of subsurface defects in thin walls using laser ultrasonics
- Increased understanding of resistance based iterative learning control of additive manufacturing with wire

Beneficiary 14 FRC

FRC will develop algorithms allowing the predicting of geometrical inaccuracies which can be used as an input for the adjustment procedure for a wide range of applications in AM. In particular:

- A thermo-mechanical modelling reduction approach for calculating shape distortion in SLM manufacturing for aero engine components
- Computational Reduction Model for Appraising Structural Effects in Selective Laser Melting Manufacturing
- Numerical Computation of Component Shape Distortion Manufactured by Selective Laser Melting.

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Advancement of knowledge								
Advancement of knowledge	In process NDT			In process NDT LUT capability for flaw detection in LMD deposition.	Repair, large scale surface coating, process control	End of the Project in 2014	no patents planned	RR, TWI
Advancement of knowledge	LMD Procedures Development for complex geometries			Increased knowhow on manufacture of complex shaped (features with overhangs) components	complex shaped geometries for components in aerospace, power generation, automotive etc	End of the Project in 2014	no patents planned	TWI
Advancement of knowledge	LMD Procedures Development for for aerospace materials			Increased knowhow on process ability of complex aerospace alloys	High temperature and high strength applications	End of the Project in 2014	no patents planned	TWI, VAC
Advancement of knowledge	In process geometrical control							TWI, ILT
Advancement of knowledge	Acceptance and inspection criteria	YES	n/a	Acceptance and inspection criteria for powder and manufactured components	Aeronautic Others (medical, tooling, automotive)	Powder: 31.03.2012 Manufactured components: End of the project in 2014	no patents planned	ITP, IK4 Lortek

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Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Advancement of knowledge	Acceptance and inspection criteria			HPC and LPT products (e.g. honeycombs)				MTU
Advancement of knowledge	Acceptance and inspection criteria							RR, WSK, TM, ITP, MTU, VAC
Advancement of knowledge	Shape distortion of whole components after additive manufacturing			Prediction of geometrical inaccuracies of complete structures after additive manufacturing	product and process design	End of the Project in 2014	no patents planned	FRC
Advancement of knowledge	Stress calculation of single passes (or layers) during SLM or LMD			Calculation of temperature gradients and creation of high stress formation during processing	product and process design	End of the Project in 2014	no patents planned	FRC
Advancement of knowledge	Modelling software							FRC, ARMINES
Advancement of knowledge	Mechanical properties							all partners
Advancement of knowledge	Mechanical properties	YES	n/a	Mechanical properties of IN718 grown by LMD-p and SLM	Structural parts. Parts for development programmes, RIGS	From 2014 onwards	no patents planned	ITP, IK4 Lortek

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Advancement of knowledge	Mechanical properties	YES	n/a	Mechanical properties of MM247 grown by SLM	Parts for development programmes, RIGS	From 2014 onwards	no patents planned	ITP
Advancement of knowledge	topological optimisation							RR, WSK, TM, ITP, MTU, VAC
Advancement of knowledge	life cycle analysis							RR, WSK, TM, ITP, MTU, VAC
Advancement of knowledge	life cycle analysis			HPC and LPT products (e.g. honeycombs)	Next generation of GTF engine family (e.g. A320 NEO; Bombardier C-Series)	2014 / 2015 onwards		MTU
Advancement of knowledge	Temperature measurement during IN718 deposition	No		Calibration routine for emissivity of IN718	Robust monitoring of LMD-w-process	To be used in demonstrator 2014	no patents planned	HV
Advancement of knowledge	Temperature measurement during IN718 deposition	No		Near-net-shape manufacturing	Robust monitoring of LMD-p-process	To be used in demonstrator 2014	no patents planned	IK4 Lortek
Advancement of knowledge	Analysis method for defect detection using LUT	No		Algorithm(s) for implementation of LUT-inspection	For in-process flaw detection	End of project 2014	no patents planned	HV, TWI

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Advancement of knowledge	Knowledge on when to use what method for additive manufacturing	No		Recommendation for AM method for manufacturing considering productivity	Novel manufacturing technologies		no patents planned	VAC, HV, …
Advancement of knowledge	Equipment for Additive Manufacturing	YES		Specification for level 2 AM cell using LMD-w			no patents planned	HV, VAC
Advancement of knowledge	Metal powder limit of use in SLM process	No		Powder recycling methodology applied to SLM process	Aerospace, automotive, medical and in general, industrial applications	End of 2013	no patents planned	IK4 Lortek
Advancement of knowledge	Fundamental knowledge about processing of high temperature alloys, e.g. IN738LC, which are used in gas turbines by SLM	no		Method/Approach for crack free processing of high temperature alloys by SLM	High temperature and high strength applications	End of project 2014	no patents planned	ILT

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Advancement of knowledge	Fundamental knowledge about processing of e.g. IN718 by HP-SLM and skin-core strategy	no		Process development of HP-SLM with IN718 and productivity improvement for IN718 according to DoW + Validation of HP-SLM for aerospace and power generation materials with high demands regarding metallurgical quality	Aerospace and power generation applications	End of project 2014	no patents planned	ILT
Commercial exploitation of R&D results								
Commercial exploitation of R&D results	In process geometrical control			In process measuring module, using line scanner technologies for fast data acquisition	Adaptive repair and manufacturing systems, Process control, complex measuring tasks inside NC machines	End of the Project in 2014	no patents planned	BCT

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	In process geometrical control			Adaptive LMD process supported by BCT OpenARMS as a separate module (process technology by partners)	prototyping, repair, new part manufacturing	End of the Project in 2014	no patents planned	BCT
Commercial exploitation of R&D results	Newly developed powder and wire							LPW
Commercial exploitation of R&D results	Equipment for Additive Manufacturing	-	-	-	-	-	-	TWI
Commercial exploitation of R&D results	Procedures for manufacturing certain parts.							RR, WSK, TM, ITP, MTU, VAC
Commercial exploitation of R&D results	Procedures for manufacturing certain parts.			HPC and LPT products (e.g. honeycombs)	Next generation of GTF engine family (e.g. A320 NEO; Bombardier C-Series)	2014/2015 onwards		MTU

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Procedures for manufacturing using specific materials.			Reduction of manufacturing lead time to produce prototype of Nozzle Guide Vanes hence reduction of time to market of new engines	High temperature and high strength applications for aeronautical components	End of the Project in 2014	no patents planned	TM
Commercial exploitation of R&D results	Procedures for manufacturing using specific materials.			Reduction of manufacturing lead time to produce prototype components of combustion chamber allowing design iteration during development of new engines	High temperature and thin components for aeronautical components	End of the Project in 2014	no patents planned	TM
Commercial exploitation of R&D results	Procedures for manufacturing using specific materials.							RR, WSK, TM, ITP, VAC

Template B2								
Type of Exploitable Foreground [19]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Procedures for manufacturing using specific materials.			HPC and LPT products (e.g. honeycombs)	Next generation of GTF engine family (e.g. A320 NEO; Bombardier C-Series)	2014 / 2015 onwards		MTU
Commercial exploitation of R&D results	Procedures for manufacturing certain parts using specific materials	YES	n/a	Procedures for manufacturing functional components with complex geometry using IN718 in SLM and LMD-p processes	Complex features in structural static parts(LMD). Parts for development programmes (SLM)	From 2014 onwards	no patents planned	ITP, IK4 Lortek
Commercial exploitation of R&D results	Procedures for manufacturing certain parts using specific materials	YES		Procedures for manufacturing high temperature materials in SLM process	High temperature applications for turbine components	from 2014 onwards	no patents planned	ITP

19 General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, Exploitation of result through EU policies, Exploitation of results through innovation

3. Report of Societal Implications

A General Information (completed automatically when Grant Agreement number is entered.

Grant Agreement Number:	266271
Title of Project:	MERLIN
Name and Title of Coordinator:	Mr John Boswell

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	No
2. Please indicate whether your project involved any of the following issues (tick box) :	NO
Research on Humans	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
Research on Human embryo/foetus	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
Privacy	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
Research on Animals	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	

Research Involving Developing Countries	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
Dual Use	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	1	7
Experienced researchers (i.e. PhD holders)	2	21
PhD Students	0	1
Other	4	16

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**3**
Of which, indicate the number of men:	3

D Gender Aspects

5.	Did you carry out specific Gender Equality Actions under the project?	○ ★	Yes No

6. Which of the following actions did you carry out and how effective were they?

Not at all effective Very effective

- ❑ Design and implement an equal opportunity policy ○ ○ ○ ○ ○
- ❑ Set targets to achieve a gender balance in the workforce ○ ○ ○ ○ ○
- ❑ Organise conferences and workshops on gender ○ ○ ○ ○ ○
- ❑ Actions to improve work-life balance ○ ○ ○ ○ ○
- ○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- ★ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ○ Yes- please specify
- ★ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ★ Yes- Course material for PhD-course in production engineering regarding LMD-p and LMD-w
- ○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ★ Aerosapce [1]:
- ○ Associated discipline[1]: ○ Associated discipline[1]:

[1] Insert number from list below (Frascati Manual).

G Engaging with Civil society and policy makers

11a	Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ ★	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ★ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ★ Yes – as a **secondary** objective (Research and Innovation, Transport)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ★ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**Publications = 12** **Conferences = 21** **Seminars/Workshops = 7**
To how many of these is open access[2] provided?	**8 Publications** **18 Conferences** **1 Seminars/Workshops**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	**4 Publications** **3 Conferences** **6 Seminars/Workshops**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ★ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ **lack of information on open access** ❑ **other[3]: ……………**	

15. How many new patent applications ('priority filings') have been made? ("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).	**None**

[2] Open Access is defined as free of charge access for anyone via Internet.
[3] For instance: classification for security project.

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	**Trademark**	**None**
	Registered design	**None**
	Other	**None**

17. How many spin-off companies were created / are planned as a direct result of the project?	None
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

★	Increase in employment, or	★	In small & medium-sized enterprises
★	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	Indicate figure: 3.5
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ★ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ★ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

★	Press Release	★	Coverage in specialist press
❑	Media briefing	★	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
★	Brochures /posters / flyers	★	Website for the general public / internet
★	DVD /Film /Multimedia	★	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	★	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]