Additive Manufacturing – Rapid Support System (AM-RS2): Concept Design of a deployable AM unit for War Theatre

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ABSTRACT

Additive Manufacturing (AM) is a highly promising technology for military environments and the defence industry. Through the combination of design freedom, technology compactness and high deposition rates, technology stakeholders can potentially exploit rapid, delocalized and flexible production. This paper aims at presenting to the NATO alliance the "Additive Manufacturing – Rapid Support System" (AM-RS2) concept, a turn-key, fully integrated/automated, user friendly, deployable system made of a "Fused Deposition Modelling" (FDM) unit, a 3D Scanner unit, a "Human Machine Interface" (HMI) and a library of pre-loaded "Pilot Geometries". The AM-RS2 system allows soldiers located in remote Area of Operation to have the capability to turn an extensive library of pilot geometries into physical tailored components when required. The AM-RS2 has been recognised by the UK MoD as an innovation and that the "use of In-Theatre manufacturing could have a real impact for the front-line response to a flexible and asymmetric threat".

1.0 INTRODUCTION

This paper aims at presenting to the NATO alliance an applied research program titled "Additive Manufacturing – Rapid Support System" (AM-RS2). The AM-RS2 program focuses in integrating Additive Manufacturing, 3D Scanning and a Human Machine Interface with pre-loaded geometries and develop a fully automatic, turn-key deployable AM system to support deployed soldiers in a War Theatre. This concept has been further developed based on the result of a workshop titled "Defining Next-Generation Additive Manufacturing Applications for the MoD" held in Bristol in 2016 where experts of the UK Defence Value Chain have participated (link). The AM-RS2 allows delivering two main capabilities to the front-line: firstly, it is an enabler of In-Theatre rapid and on demand manufacturing and secondly it delivers late-stage customisation. The system, through a user-friendly interface, allows operators to select, customise and print rapidly components for their equipment, kits and weapon systems, when these are required. Providing soldiers deployed in remote Area of Operation (featured with scarcity of resources) such system may deliver a strategic advantage.

2.0 RESEARCH METHODOLOGY

The methodology applied is based on Systems Engineering principles developed by SEBoK, (2014) NASA, (2007) INCOSE, (2015) and is outlined in Figure 1.

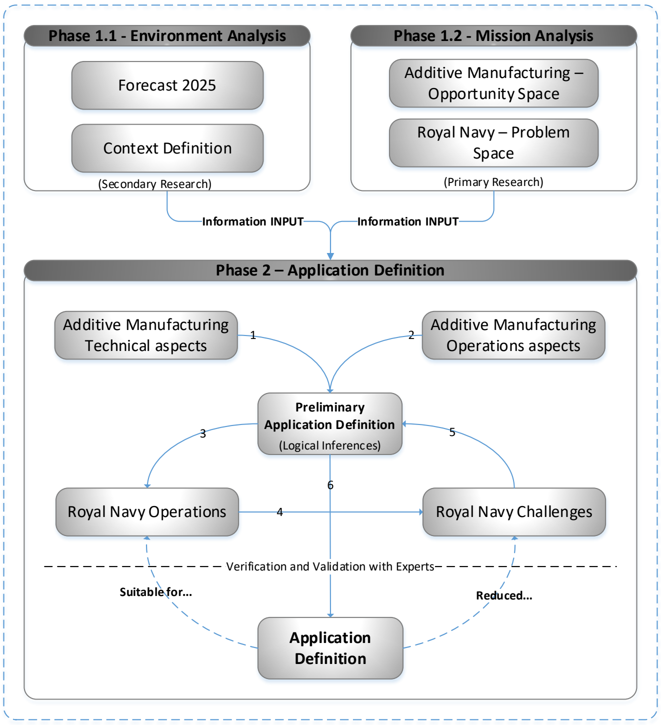

Figure 1 - Multidisciplinary Methodology

The methodology discerns technical and operations aspects of the technology and combined with macro and micro environment aspects allows defining optimal next-generation applications of Additive Manufacturing.

- Phase 1.1 “Environment Analysis” is made of a context definition and outlines a roadmap of how the environment will change in the future. This is mainly carried out with secondary research and sources of information are carefully selected based on reliability.

- Phase 1.2 “Mission Analysis” represents a critical activity as this is where the “Context - Problem Space” and “Technological - Opportunity Space” are defined. This is primarily based on primary research and experts were identified from various parts of the whole UK Defence Value Chain. This involved eliciting, capturing, manipulating and validating through expert judgement.

- Phase 2 “Application Definition” is a concept development activity based on a conceptual framework which is fed by the results of Phase 1.2 ”Mission Analysis”. This approach allows a systematic AM application definition.

Firstly, organisations of the UK Value Chain have been contacted and requested to nominate an experienced and reliable source of expertise. The information elicitation process has been carried out through an induction of the activity aim and through the use of structured charts. Once the information has been captured the results have been analysed. The results have been displayed on an A3 chart with references which allowed the author to have an exhaustive understanding of the overall inputs received. This allowed the author to draw conclusions and report a first draft of the activity. Finally, the draft has been sent to the experts for verification and validation purposes and iterative improvements have been made.

3.0 WORKSHOP RESULTS

The inputs received by the UK Defence Value Chain in the workshop share similarities. The key players of the UK Defence Value chain outlined the same vision on AM to be exploited for delocalisation of manufacturing near the point of use or in different stages of a military supply chain such as port, support vessels or forward bases. The vision of AM in defence is mainly: to print, next to point of use, critical-to-availability components in order to eliminate or reduce the "Logistic Delay Time" (LDT) and improve availability of "Complex Engineering Systems" (CES) or equipment, to repair components and structures when battle damages or accidents occur and recover capability, to print low value consumables inside the platform in order to reduce some inventory (Busachi et al., 2016a).

Table 1 - AM Opportunities

Technical Opportunities	***Operational Opportunities***
Design for Multifunctionality	Enabler of Just-in-Time
Compactedeness of technology	Enabler of Continuous Improvement (CI)
Elimination of sub-assemblies	Ability to produce highly tailored components
Design Freedom	Delocalisation next to the point of use
Rapid Prototyping	Ability to process random geometries
Concurrent deposition of different materials	Enabler of product development with end user

AM (generic) technical opportunities, which are generally shared (with different levels) among the various AM process methodologies have been outlined and are compactness of the technology, short cycle time for production and prototyping, design freedom, prototyping opportunity to test design in early stage, design for multi-functionality/lightweight/high-efficiency/enhanced-functionality, production of fully dense metal/plastic/ceramic parts, concurrent deposition of different materials.

Furthermore, AM (generic) operation aspects have been outlined. These AM operations aspect are based on "Manufacturing System Engineering", "Lean Manufacturing" principles and "Lean Product and Process Development" and are possible due to the delocalisation of AM production next to the point of use and through the involvement of the end-user:

- AM as an enabler of "Continuous Improvement" in the work place: RN operators, while deployed carry out their daily activities (with standard tools, jigs, equipment and kits) through which they mature a direct experience. During this experience, they might develop/generate ideas in order to improve a process. If a platform has manufacturing capability based on AM they can convert ideas into functional products.

- AM is an enabler of Design Freedom, it is able to print rapidly any kind of geometry without the need to setup the machine or change tools: this aspect fits very well if we consider that AM is deployed in a platform to "serve" various "Complex Engineering Systems" (CES) made of an extended number of components which all differ one from another in terms of geometry. A sole AM machine is able to manufacture all of the components when these will fail.

- AM as an enabler of improved Product Development: similar to the first point, AM allows to improve the Product Development. End-users, through the utilisation or direct experience develop/generate naturally ideas to improve their daily routine. AM as an enabler of CI is given by a combination of delocalisation of manufacturing next to the point of use, involvement of end-user (which detain the direct experience) in the PD and rapid prototyping capability to test the designs in the early stage.

- AM as an enabler of "Just-in-Time" (JIT): Considering the delocalisation of manufacturing within the platform, the "Logistic Delay Time" (LDT) is eliminated or dramatically reduced, moreover AM allows to achieve short CT of production. This combination allows to establish JIT principles which allows you to reduce the stocks of finished goods and produce only the components that you require and when you require them.

- AM as an enabler of mass customisation: AM allows you to produce highly tailored products to your needs and unique features. This aspect is fundamental when you require special tools to perform an operation, when you have to produce a prosthesis tailored to the human body unique features or to provide special tools/small arms/body armours to tier-1 operators.

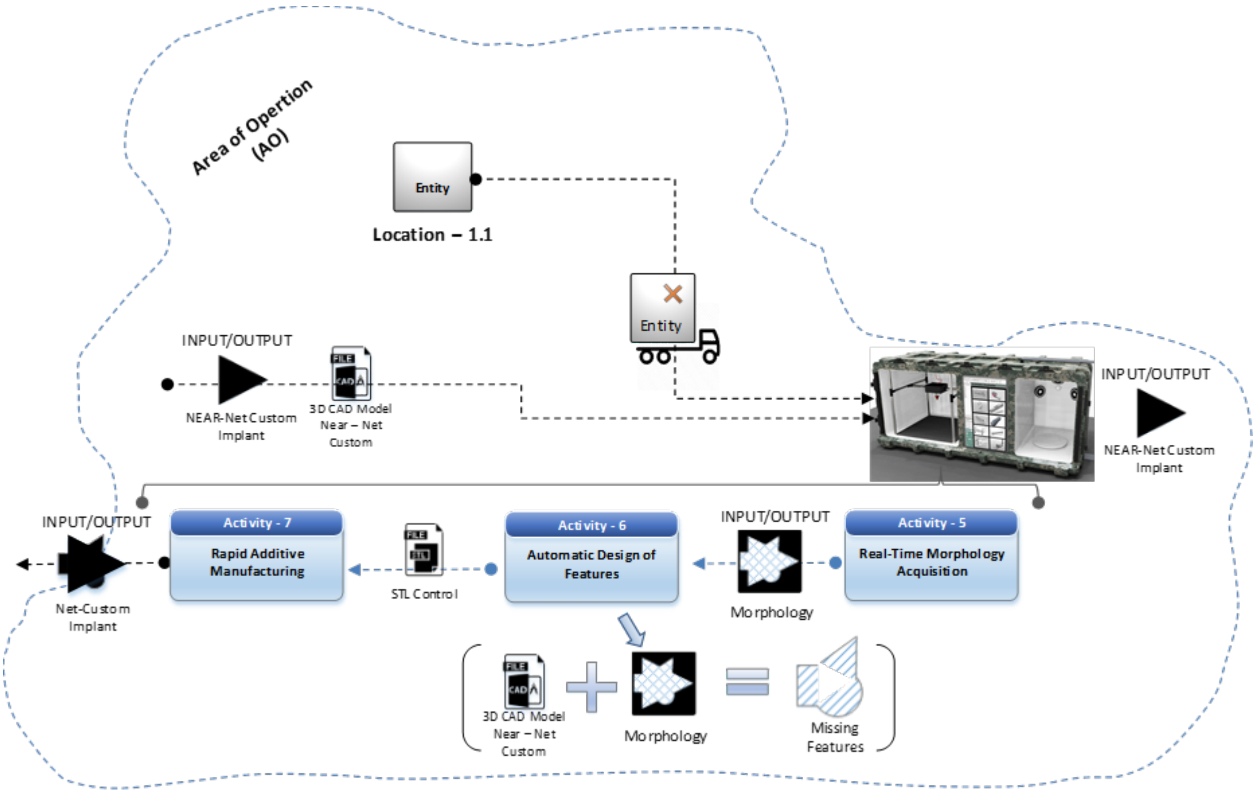

Figure 2 - AM Deployed in AO

The workshop outlined the next-generation most promising Additive Manufacturing applications for the Ministry of Defence (MoD) of the NATO Alliance. The result is given by a combination of technical aspects such as compactness of technology, fully dense production, design freedom, rapid production and operations aspects such as enabler of JIT, ability to process random geometries and ability to delocalise manufacturing to different stages of a military logistic:

- Delocalise manufacturing within the platforms or develop deployable AM units for forward bases to support specific soldier's needs and tailor body armours, kit, special tools or small arms to the unique operators features and mission requirements.

- Develop deployable AM units to support disaster relief missions with the ability to print simple plastic medical components (valves, pipes, fittings) and more sophisticated AM units to print temporary or permanent tailor-made prosthetics.

- Delocalise manufacturing within the platforms or develop deployable AM units for forward bases to print or repair "Unmanned Ground/Sea/Air Vehicles" (UV).

4.0 AM-RS2 CONCEPT DESCRIPTION

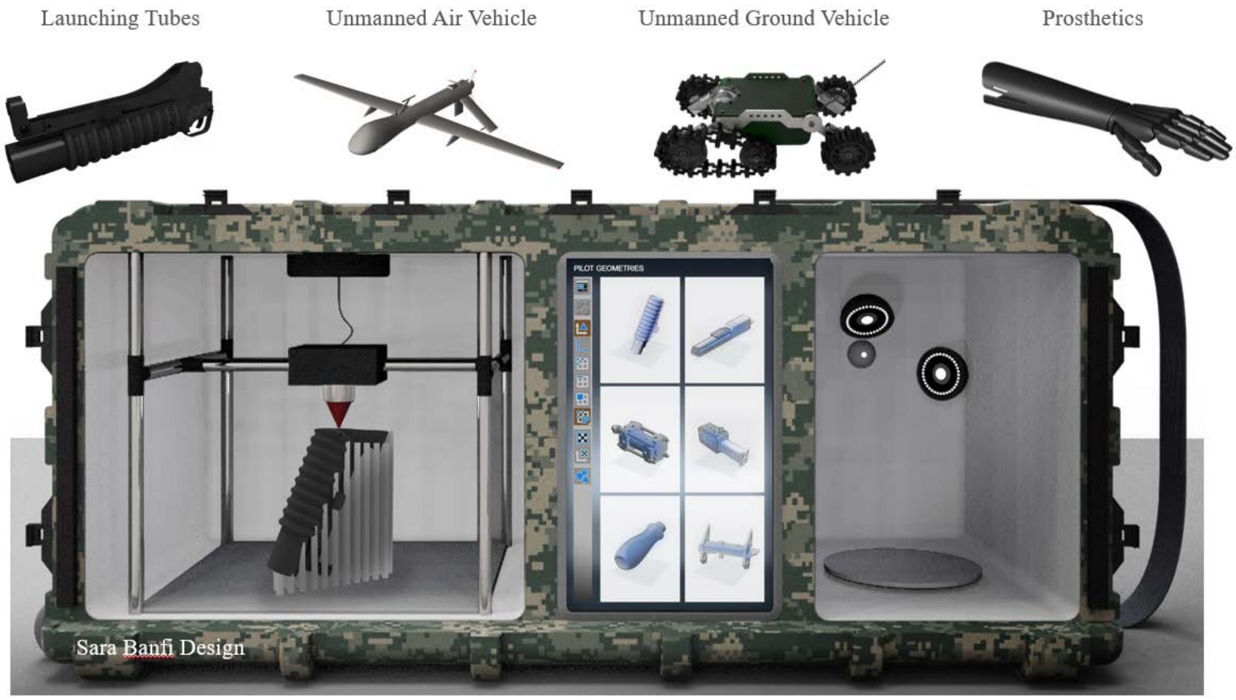

Figure 3 - AM-RS2 3D Model

The “Additive Manufacturing – Rapid Support System” (AM-RS2) is a turn-key, fully integrated/automated, user friendly, deployable system made of a “Fused Deposition Modelling” (FDM) unit, a 3D Scanner unit, a “Human Machine Interface” (HMI) unit and a library of pre-loaded “Pilot Geometries”. The AM-RS2 is intended for delocalised manufacturing, in-theatre next to the point of use and aims to support operators during their daily tasks. The innovation relies in both, the full integration of the system and the pre-loading of “Pilot Geometries” which are firstly ready to be customised based on mission requirements/operators' needs and secondly redesigned for enhanced performance, modularity, multifunctionality and lightweight.

Figure 4 - AM-RS2 Box opening

AM allows designers to access freeform design and achieve new geometries which would not be feasible with conventional manufacturing systems. Moreover, if AM is associated with appropriate design methodologies, topology optimization software and structure analysis tools, the technology can provide improved components in terms of functionality and efficiency. The AM – RS2 may be employed for different missions such as 1) improving performance of soldiers through the rapid production of highly tailored, redesigned for enhanced performance, plastic, non-critical components of drones, special tools, kit 2) rapid prototyping for in-theatre equipment modifications and repairs and 3) support crisis relief mission through the production of standard plastic medical components. AM provides the capability for rapid, delocalised and flexible manufacturing which has a major impact/advantage when components are required in an "Area of Operation" (AO) featured with extended and disrupted supply chains.

Figure 5 - AM-RS2 deployed in a Patrol Base

The AM – RS2 turn-key and deployable systems are engineered for deployments in "Area of Operation" (AO) located in remote areas of the world featured by: 1) extended and potentially disrupted supply chains (disrupted by natural agent or hostile entities), 2) scarcity of resources and 3) harsh environments. The AM – RS2 systems yield the highest impact/benefit in AO where the "demand" of components, equipment and customised Operator's systems cannot be planned and forecasted due to high degrees of uncertainty.

Figure 6 - AM-RS2 Transportability

AM – RS2 are particularly suitable for "first-time-in" deployments in new AO's where operators may not be fully aware of what they will require given the inexistence of previous experience. Having an extensive library of pre-loaded geometries and the capability to turn these geometries into highly customised components to the point of use will benefit the Operators dramatically.

4.1 AM-RS2 System Elements

This section provides more details on the AM – RS2 outlining a high-level description of software and hardware elements. As explained previously, the AM – RS2 is tailored to a predefined mission that will results in different configurations of the system. A generic AM – RS2 structure is outlined in Figure 7 and provides a visualisation of the system concept without any references to dimensions but only to generic system elements.

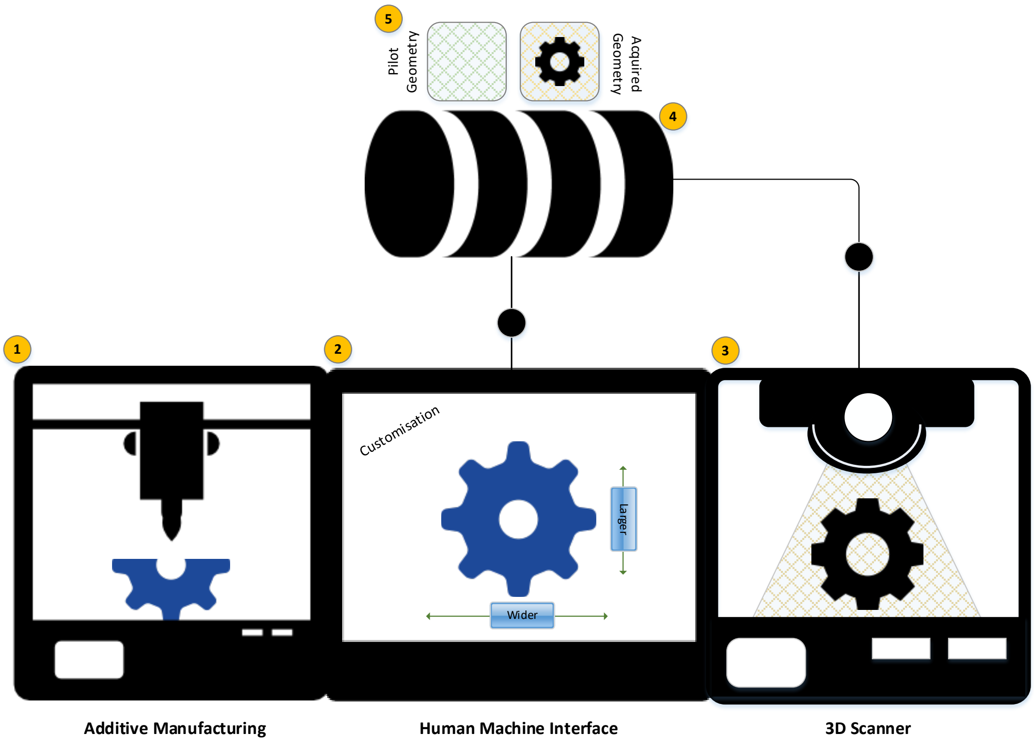

Figure 7 - AM-RS2 Modules

An AM – RS2 is made of five exclusive but integrated system elements, these are:

1. Element – 1, is a “Fused Deposition Modelling” (FDM) module which allows users to convert geometries stored as 3D files into physical objects. FDM technology allows to deposit plastic filaments in a layer-by-layer way, this process allow to exploit design freedom. The build chamber size is tailored to the mission of the AM – RS2 and has to be able to incorporate the largest component that has been included in the “Pilot Geometries”. Moreover, the build chamber can be a rigid structure with a fixed building volume, or a flexible structure in which case the chamber is extensible.

2. Element – 2, is a “Human Machine Interface” (HMI) and a “Central Processing Unit” (CPU) which integrates all the system elements and allows the user to operate with a high degree of user-friendliness the turn-key system. Through the HMI the user is able to access a library of components which represent the “Pilot Geometries” (STL Files) stored into a database. After the user selects the required component, a pop-up customisation module will allow the user to customise the geometry based on his needs and operator’s mission requirements. The user can retrieve immediate feedback on deposition time and cost of the modified geometry and decide whether to print or not. Through this module the user can trigger the command to print and the CPU will control the deposition. Finally, the HMI allows also to control the 3D scanner to acquire non pre-loaded geometries which are found in the “Area of Operation” (AO) of the deployed AM – RS2.

3. Element – 3, is a 3D scanner which has been included into the AM – RS2 in order to acquire non pre-loaded geometries providing more functionality to the system.

4. Element – 4, is a database removable unit which is critical to the system as it contains the stored "Pilot Geometries".

5. Element – 5, are the "Pilot Geometries" which represents the core of the AM – RS2. Firstly, plastic, non-critical components have to be identified and selected. This is possible through a study of the breakdown structure of the systems used in the war theatre or the "Area of Operation" (AO) (i.e. drones, weapon system, kit). Once the components have been selected, these need to be reverse-engineered in order to acquire a 3D geometry stored as a CAD file. Afterwards the acquired geometry needs to be optimised for enhanced performance, lightweight, multifunctional, modularity. This is possible through the combination know-how, design methodologies, topology optimisation and structural analysis tools. Once the optimised design is completed, it has to be validated in a virtual environment. Finally, the validated and optimised geometries will be converted into a more generic design which is ready to be customised, these designs are called "Pilot Geometries" and are stored in the database, retrievable through the HMI and ready to be printed.

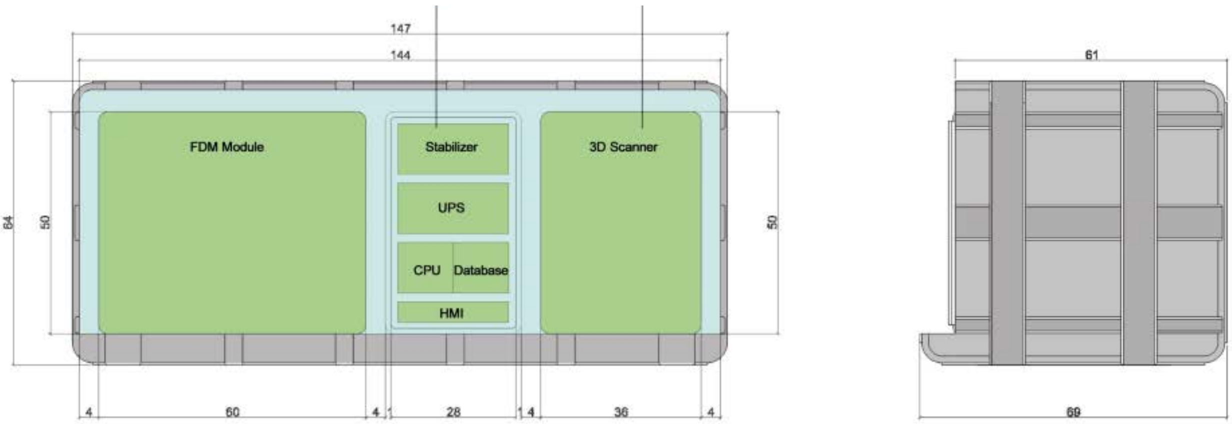

Figure 8 - AM-RS2 Layout

The deployable unit has to be water proof, able to float in water and the bottom has to be designed for dragging on dirt tracks and sand. With a total volume of 0.57 m3 a standard ISO container (small) can fit easily 27 RS2 units and extensive spare of Raw Materials. A generic layout is outlined in Figure 8 and is representative of the area of an RS2, nevertheless the dimensions are subjective to change based on the RS2 mission.

Figure 9 - AM-RS2 Compact design

The AM-RS2 may be designed with reduced volume with an external 3D Scanner and an extensible HMI unit as outlined in Figure 9.

4.2 Capability Delivered & Concept of Operation

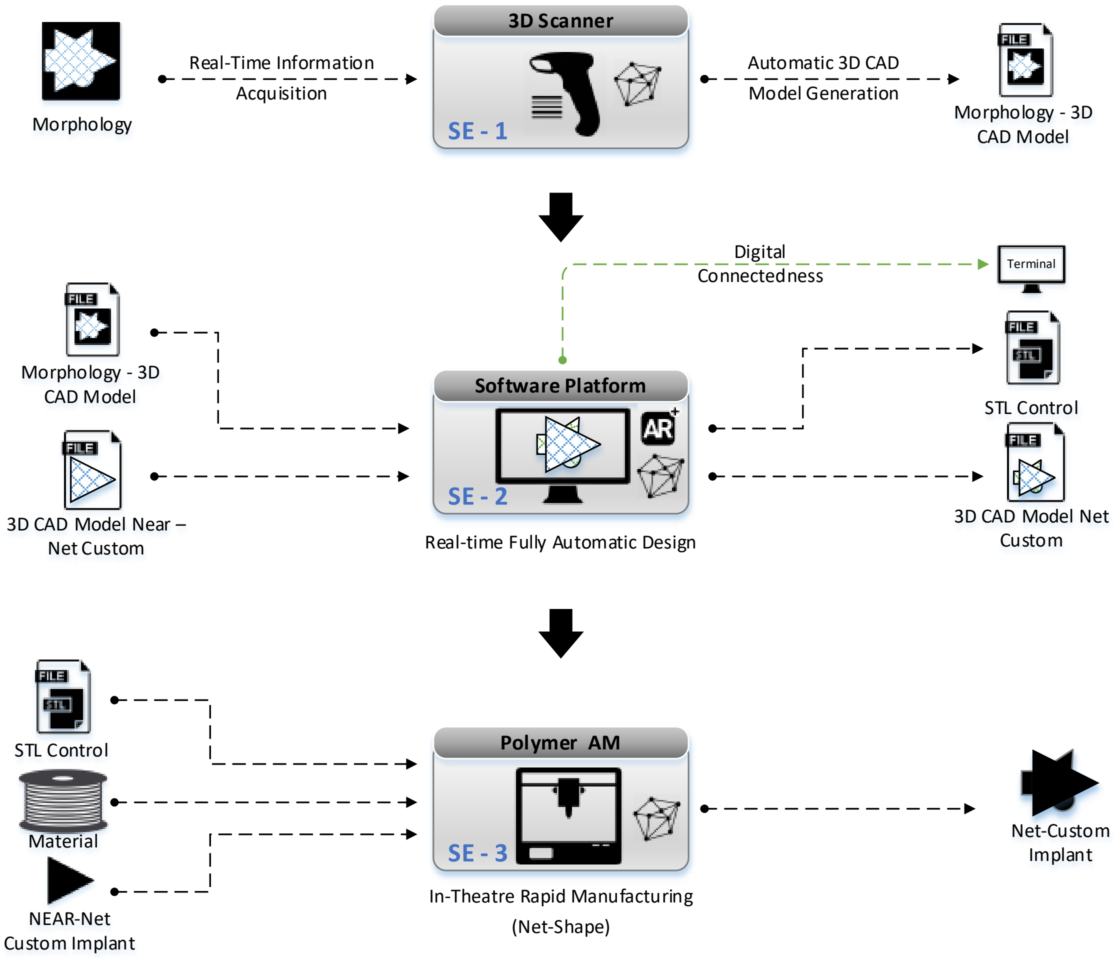

Figure 10 - AM-RS2 Concept of Operation

Deploying the AM-RS2 in an Area of Operation or the Front-line, provides Operators two main capabilities. Firstly the AM-RS2 is an enabler of In-Theatre rapid, on-demand manufacturing and secondly it provides the soldier for late-stage customisation. Moreover, having a 3D Scanner allows the Operators to acquire geometries and morphologies in-field.

- Concept of Operation – 1: an Operator's component is broken and needs to be replaced with a new one or a temporary replacement. The Operator access the Library through the HMI, selects the required geometry and if required the Operator can tailor it to his needs. Through the software tool, the Operator does not require to optimise the geometry for printing, it is performed automatically. Once the geometry has been selected and modified the operator can print it directly through the AM module.

- Concept of Operation – 2: an Operator needs to repair or modify a component. The Operator places the component in the 3D Scanner. Through the HMI the Operator can acquire the morphology or geometry of the component. Once the morphology or geometry is stored the Operator can select a Pilot Geometry and place it over the acquire geometry. Through the software tool the operator can customise the Pilot Geometry on top of the acquire geometry and morphology and print it automatically when ready.

4.3 Human Machine Interface (HMI)

The AM-RS2 is controlled by a Software Platform, the Operator interacts with the system through a user-friendly Human Machine Interface (HMI) which is made of three modules outlined in Figure 11: 1) Geometries Module, 2) Customization Module and 3) Optimisation Module.

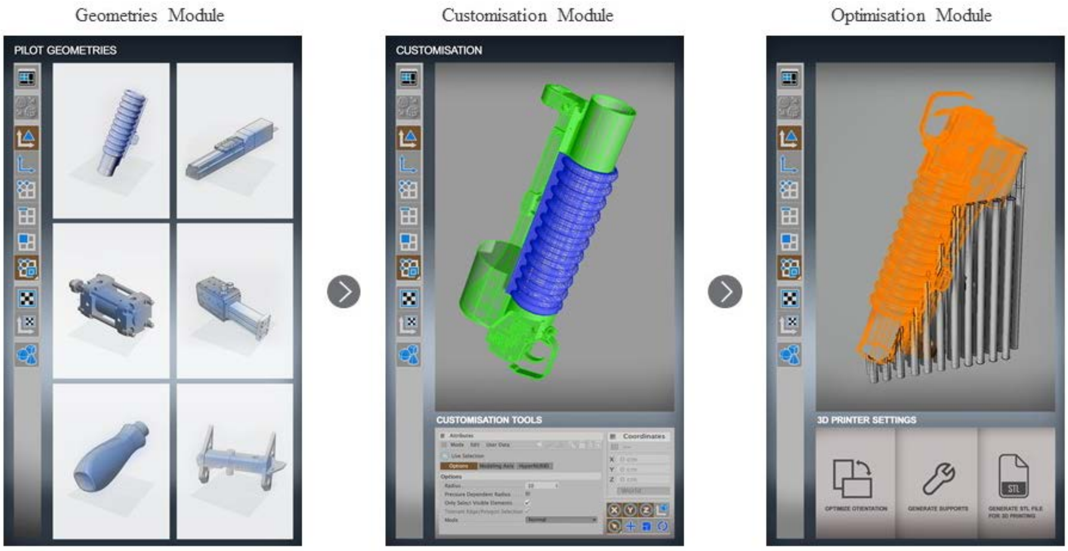

Figure 11 - HMI Sequence of Operations

To initiate the AM-RS2 system the Operator must follow a sequence of three operations. As outlined in "Concept of Operation – 1" the Operator needs a component, therefore through the Geometries Module he can select the "Pilot Geometry" he requires. Afterwards the Operator needs to customise the "Pilot Geometry" (in blue) through the Customization Module. The Operator can choose between different options stored within the module and can add them to the Pilot Geometry. The customisation features are outlined in green.

Figure 12 - AM-RS2 in operation

Once the customisation of the Pilot Geometry is completed, the Operator needs to consolidate the component and through the Optimization Module, he is able to optimise the orientation of the part and generate automatically the supports. This module also generates the STL control file for the FDM module. Once the STL file is generated, the system automatically prints the component (in black) with the FDM.

4.3.1 Geometry Sequences

The geometry sequence is outlined in Figure 13 and consists of six semi-automatic steps.

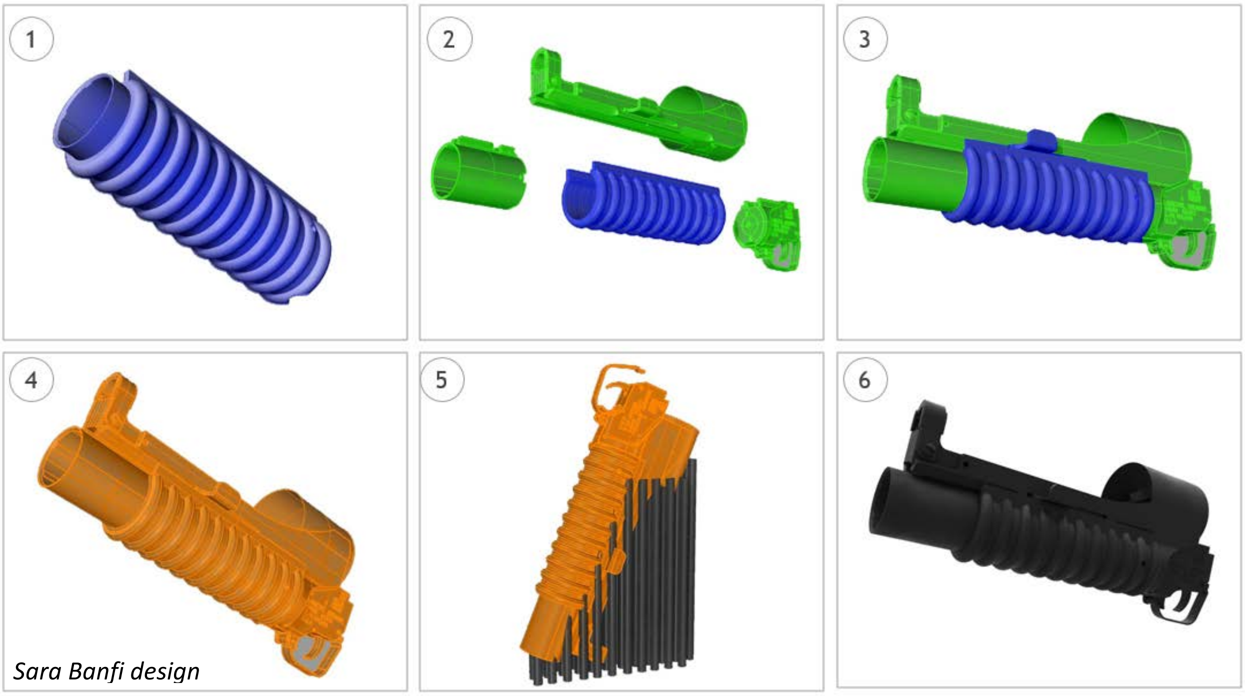

Figure 13 - Geometry Sequence

The first step is the selection of the Pilot Geometry (in blue) which is stored in a library accessible through the HMI. The second step is the customisation of the Pilot Geometry where the Operator selects the features (in green) he wants to add to the Pilot Geometry. The third step consists in an automatic consolidation of Pilot Geometry and selected features. The fourth step is an automatic slicing of the consolidated geometry into layers and conversion into an STL file. The fifth step consists in an automatic optimisation of the orientation of the part to enhance mechanical properties and minimise deposition time. Moreover, the supports (in black) are automatically generated. The sixth step is the printed and assembled system.

4.3.2 Pilot Geometries Database

Figure 14 - Pilot Geometries examples

The library contains an extended number of Pilot Geometries of systems and components required by the Warfighter in an Area of Operation (AO). The geometries stored can be of Launching Tubes, Unmanned Air Vehicles, Unmanned Ground Vehicles, Prosthetics and generic Components. The Operator is able to print the whole system or components as spares. Moreover, through the Customisation Module the Operator can tailor the system or component to his, or mission requirements. The database of the AM-RS2 can be pre-loaded, in advance prior to deployment, with different Pilot Geometries based on the requirements of the mission. The following sections provides provide more detail of the System Configurations of the AM-RS2.

4.4 Systems Configurations

The AM-RS2 can be tailored to various missions to which a system configuration is associated.

- System Configuration – 1 → "Rapid Operator Support System" (ROS2)

Mission: "to support deployed and dismounted soldiers in the War Theatre by satisfying their needs of highly customised and improved performance components whenever they require them and tailored to an operator's mission"

Description: Through the deployment of the ROS2 to the front-line, the ground Armed Forces will benefit of rapid, delocalised and flexible manufacturing (Busachi et al., 2015). The ROS2 provides soldiers the capability to tailor their systems such as kit, special tools, weapons and drones to a mission. Moreover, through the pre-loaded geometries stored in the database, the soldier has the availability of an extended number of spares (the only delay is given by the deposition itself).

- System Configuration – 2 → "Rapid Logistic Support System" (RLS2)

Mission: "to support the Helicopter Logistics in the War Theatre by proving highly tailored packaging structures to minimize the volume and maximise platform's load"

Description: The DE&S – MoD has reported an inefficient use of Helicopter logistics in War Theatre due to the inability to plan and forecast the required packaging and the inexistence of "modular packaging systems". This results in Chinooks taking off with low utilization of payload capacity (i.e. the available space is obstructed by unnecessary packaging). Low utilization of helicopter's payload capacity results in higher frequency of flights, higher costs and times and exposure to threats in hostile operating environments.

- System Configuration – 3 → "Rapid Prototyping Support System" (RPS2)

Mission: "To support modifications and repairs of ground/air platforms and equipment in the War Theatre by providing a design tool and prototyping capability"

Description: the DE&S – MoD has reported that current process for modifications and repairs of platforms, equipment involves the acquisition of measurements, and a high-level sketch carried out in the War Theatre and sent back to UK for final design and manufacturing. This process may lead to inaccuracies and unintentional omissions of data & information by the ground forces resulting in improper designs. By delocalising the RPS2 the ground forces are able to prototype, test and validate immediately the design and send back to the UK the final 3D drawing for manufacturing.

- System Configuration – 4 → "Rapid Crisis Support System" (RCS2)

Mission: "to provide immediate aid to population affected by disaster"

Description: Having an extensive library of pre-loaded geometries and the capability to turn these geometries into highly customised components next to the point of use will benefit dramatically the population affected by disaster. The RS2 is a fully integrated, easy to use manufacturing system sided by a 3D scanner which allows operators to acquire unique physical features of the body of the wounded and tailor the medical components to his body. Moreover, the RS2 is engineered for rapid deployments by air, land and sea making it a rapid response to the occurrence of needs in the affected areas. The RS2 Human Machine Interface sided by the library of "Pilot Geometries" make the turn -key system highly user friendly allowing untrained personnel to operate the system.

4.5 Case Studies

The first case study involved the assessment of printing a whole Unmanned Air Vehicle (UAV).

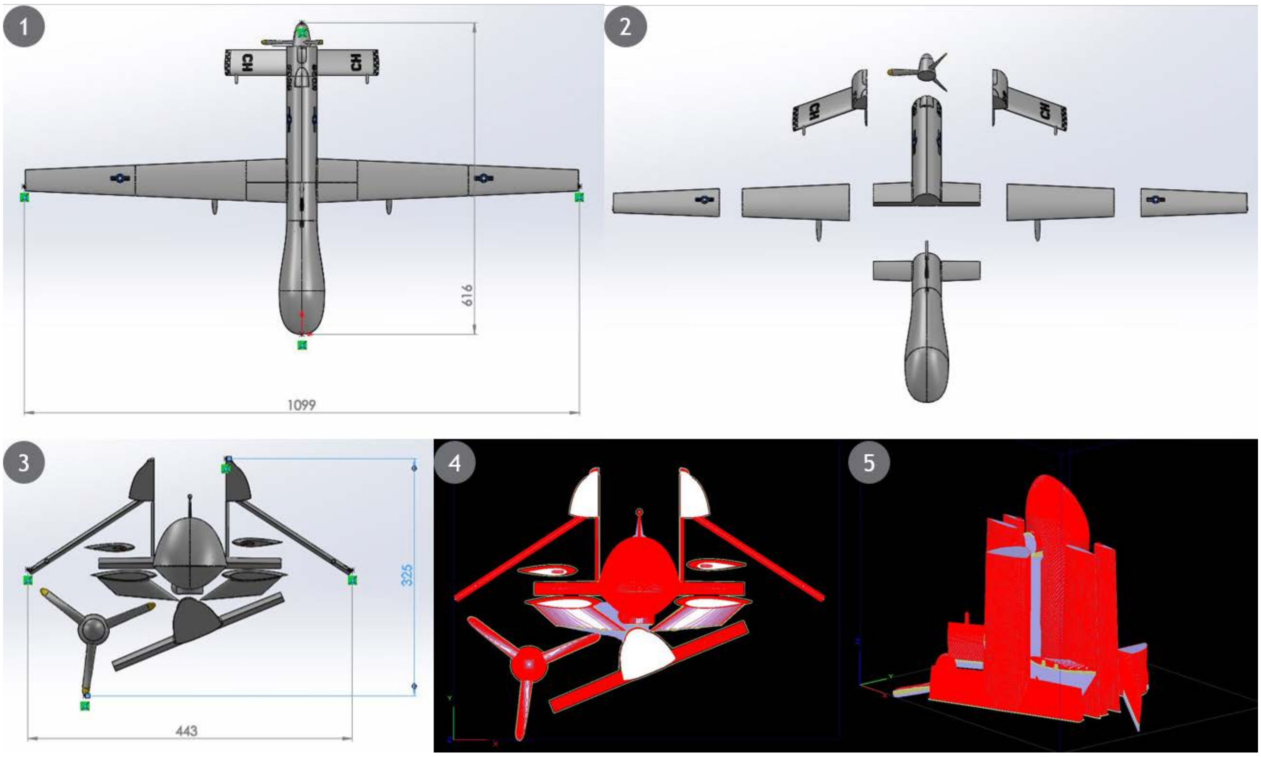

Figure 15 - Mini Predator

The first step involves the definition of the required dimensions of the UAV (tailoring). The second step is an automatic explosion of the system into its constituent elements. The third step involves an automatic build packing. Finally, the CAD file is converted into an STL file and the build is orientated to reduce build time.

Volume of Material	970.828 cm³
Print Time	20.75 hours
Deposition Rate	46.78 cm³/hr
Geometry Complexity	2

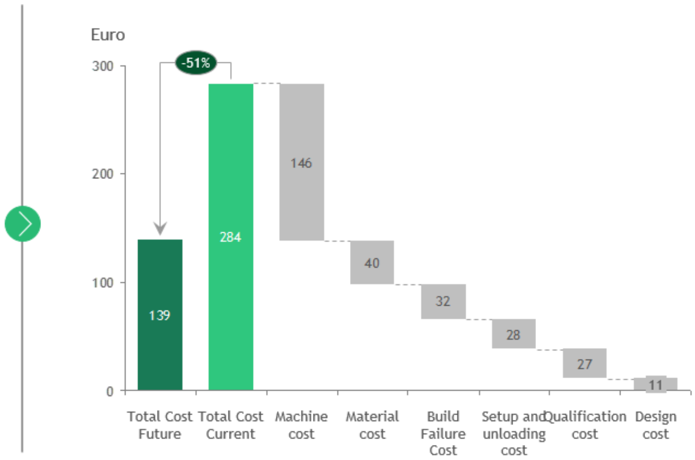

Figure 16 - Drone CBS

In Figure 16 the Cost Breakdown Structure of the UAV is outlined. With a printing time of 20 hrs, a total cost of EURO 284 (estimated – 50% reduction) the feasibility of printing the UAV with the AM-RS2 is outlined.

The second case study involved the assessment of printing a tailor made grenade launcher.

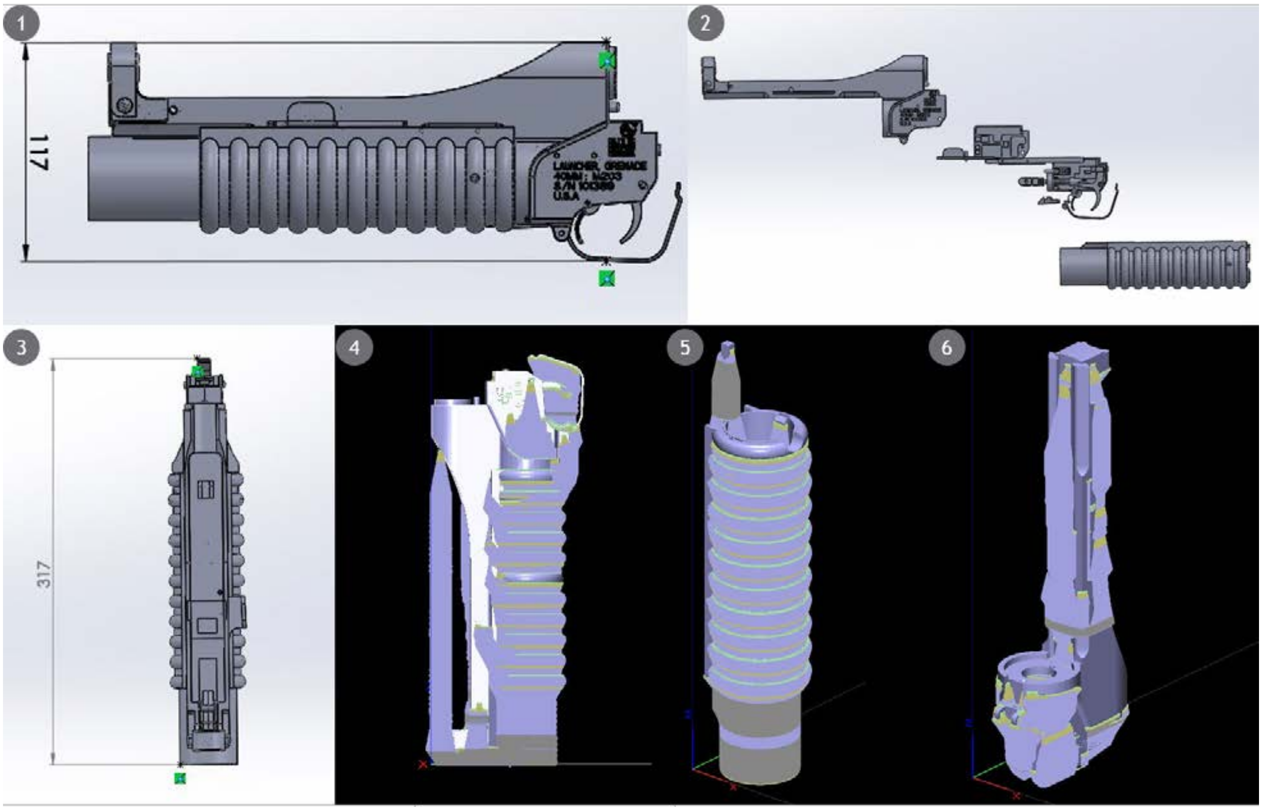

Figure 17 - Grenade launcher

The first step involves defining the desired calibre of the launcher. The second step is an automatic explosion of the system into its constituent elements. The third step involves an automatic build packing. Finally, the CAD file is converted into an STL file and the build orientation is optimised to reduce time.

Grenade Launcher

Volume of Material	553.626 cm3
Print Time	21 hours
Deposition Rate	21.92 cm3/hr
Geometry Complexity	5

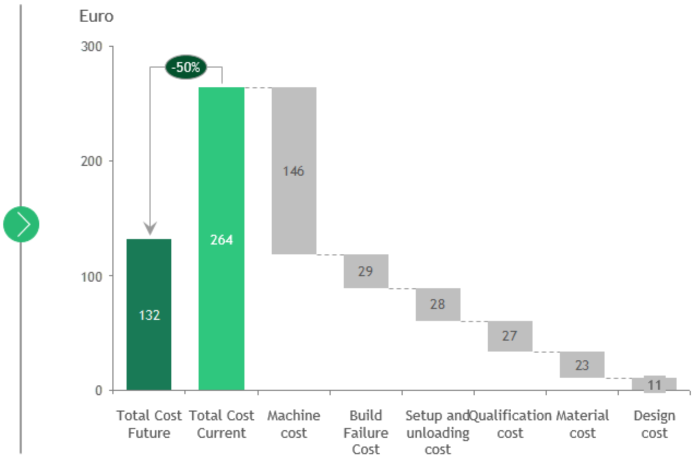

Figure 18 - Launcher CBS

In Figure 18 the CBS of the launcher is outlined with a total cost of EURO 264 (estimated – 50% reduction) and CT of 21 hrs. The high printing time is given by the complexity of the geometry of the component, which affects negatively the deposition rate.

5.0 EXPLOITATION BEYOND PROOF OF CONCEPT

The AM-RS2 program starts with a feasibility study, outlined in Figure 19, which has to be carried out with the involvement of the MoD and through interactions with the Royal Army, the Royal Marines Commando and the Royal Engineers. The feasibility study (TRL-3) aims to demonstrate the costs/benefits/feasibility of deployed FDM technology in the front-line and assess the value added of the optimised geometries using “High Performance Engineering” principles. The feasibility study focuses only on the ROS2 i.e. supporting soldiers.

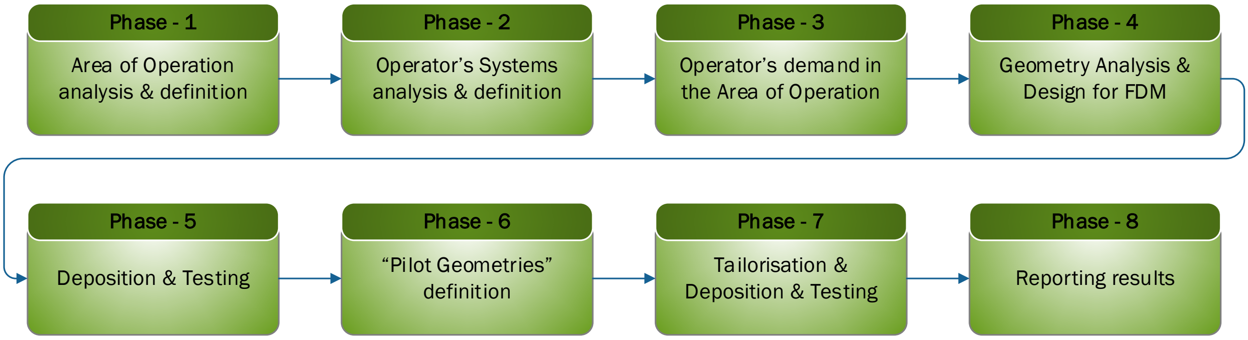

Figure 19 - Research & Technology process

The questions that the feasibility study will address are the following:

- “What are the costs and benefits of deploying FDM capability with related library of “Pilot geometries” in the Front-line?
- Is it feasible in terms of time and cost? Is it worth developing a deployable turn-key FDM + 3D scanner system to support soldiers?
- Is the deployed FDM system able to cope with “responsiveness to operation tempo”?
- What are the typical CT for depositing the biggest and smallest components?
- Is it possible to tailor components, through the customisation of “Pilot geometries”, to Operator’s needs and mission requirements?
- Is it possible to provide real battle advantages to Operator’s by tailoring their sub-systems? (Quantify the benefits – i.e. overall weight reduction)

The AM-RS2 program has the ambition to develop three different systems: 1) ROS2 to support soldiers, 2) RLS2 to improve the helicopters logistics and 3) RPS2 to support operators on modification and repair activities. Prior to capital investment and higher TRL activities, a feasibility study has to be carried out in collaboration with the MoD to assess firstly the feasibility of deployed FDM capability and secondly to inform and persuade MoD’s personnel.

The feasibility study is a combination of analytical, engineering & design and assessment studies which includes also prototyping, laboratory testing and field testing of optimized and FDM printed components.

- Analytical studies – Phase 1/2/3: to define the context and gather information on the Area of Operation, the systems used by the dismounted and deployed operators and identify what fails in the front-line and what is required by the operators.

- Engineering & Design – Phase 4: to study the "System Breakdown Structure" (SBS) of the operator's system, identify which geometries can be processed for FDM, study the geometries, optimize the design for enhanced performance, lightweight, multifunctional and modularity, optimize it for FDM (reduced CT and supports) and finally validate the novel design through virtual engineering methods.

- Prototyping & Testing – Phase 5: to print the optimized geometries with an FDM system, retrieve data on CT and cost, test the prototypes in a laboratory environment, finally test the prototypes in field, and gather results of test for comparison in Phase 8.

- Engineering & Design – Phase 6: to demonstrate the concept of "Pilot Geometries", where, an optimized geometry is "generalized" and made easy to be tailored to operator's needs and mission requirements. This may involve also the development of a Graphical User Interface.

- Prototyping & Testing – Phase 7: to print highly customized and optimized geometries with the FDM system and perform same testing as in Phase 5 and gather results.

- Assessment study – Phase 8: to carry out an assessment of the feasibility of FDM and Pilot Geometries to support operators in the front-line. Gather all results, perform a comparative study between geometries and evaluate what FDM can do for the operators outlining quantitatively time, costs, benefits and investment required for developing the ROS2.

Following the feasibility study, a detailed design of the AM-RS2 has to be developed to define a detailed "Bill of Material" (BoM) and components and materials have to be acquired in order to start the assembly of the system. While the technology integration and system assembly does not represent a challenge, the software side is. A collaboration with a software house might be necessary to access their experience in developing operating systems for Additive Manufacturing systems.

In order to engineer and manufacture a functional prototype, it is estimated a timeline of 10 to 15 month with 3 resources employed full time and an investment of £160,000 for the equipment and £80,000 for the software. Has to be outlined that a strong collaboration with the end user has to be established as the AM-RS2 are tailored to the end user needs and detailed analytical work has to be carried out.

Table 2 - Work Packages

Objective	Tasks
To build a prototype Fused Deposition Modelling (FDM) Additive Manufacturing (AM) machine to build components.	• Generation of Detailed Design Specifications • Generation of Hardware Specification • Generation of Automation Software Specification • Machine Design (Mechanical, Electrical and Automation) • Machine Build • Machine Development and Testing • Continuous Improvement and remedial Work • Manufacture Representative parts • Prepare and Develop Testing Equipment • Product Testing QA
System Software and User Interface (UI) Development	• Scanning technology benchmarking, evaluation and selection. • Scan capture software development • Scan and CAD integration • UI Development • Development and testing

6.0 FEEDBACK FROM THE MINISTRY OF DEFENCE (MOD)

The Centre of Defence Enterprise of the Ministry of Defence of the United Kingdom recognised the AM-RS2 program as an innovation stating that the "use of In-Theatre manufacturing could have a real impact for the front-line response to a flexible and asymmetric threat".

Moreover the MoD outlined that "there could be benefit to In-Field Additive Manufacturing capability for both the dismounted soldier and "Forward Operating Bases" (FOBs) and that "the MoD was enthusiastic that the program brings together the multiple technologies of AM, Digital Scanning and HMI Design Tools".

Furthermore the AM-RS2 has been submitted to the Army Warfighting Experiment and the MoD's Force Exploration Wargame and which focused on high level operational level. The AM-RS2 has been recognised as having a strong impact on tactical level especially in resupplying kit such as launching tubes or small grenade launchers as follow up on operations.

7.0 AM – RS2 CHALLENGES AND LIMINISTATIONS

This paper presented a concept matured till TRL-3 on a fully integrated FDM + HMI + 3D Scanner system to print plastic non-critical components in delocalized environments. The system is still a concept featured with many uncertainties and un-defined details on designs, dimensions, reliability and capability. Major aspects which needs to be clarified in future work are: Lack or knocking out of power supply, Effect of shock waves and projectiles from blasts/explosions on the stability of the printer to enable interruptible printing, i.e. filament becomes stuck in feed tube, XYZ motor gets knocked out of position but must retain last printed position to continue, Environmental conditions, hot, cold, wet, dry dusty, Ease of repair in theatre, Supply of materials and spares and Data security. Moreover additional challenges are: the material properties and homogeneity in material properties as well as post-processing of the printed material

8.0 CONCLUSIONS

This paper presented the AM-RS2 applied research program which aims at developing a deployable AM unit to support soldiers located in remote Area of Operation. The AM-RS2 systems provides Operators two main capabilities. Firstly the AM-RS2 is an enabler of In-Theatre rapid, on-demand manufacturing and secondly it provides the soldier for late-stage customisation. Moreover, having a 3D Scanner allows the Operators to acquire geometries and morphologies in-field. The AM-RS2 has been recognised by the UK MoD as an innovation and its relevance for asymmetric and flexible threats has been outlined.

9.0 REFERENCES

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Figure 20 - AM-RS2 deployed in a Patrol Base

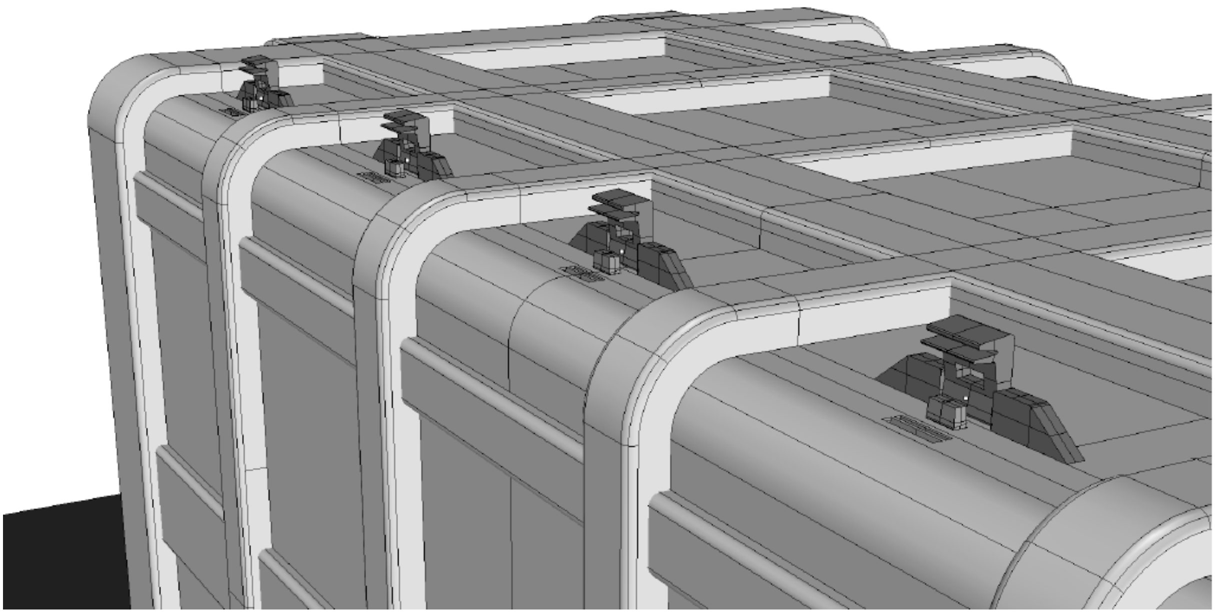

Figure 21 - Details on locking system

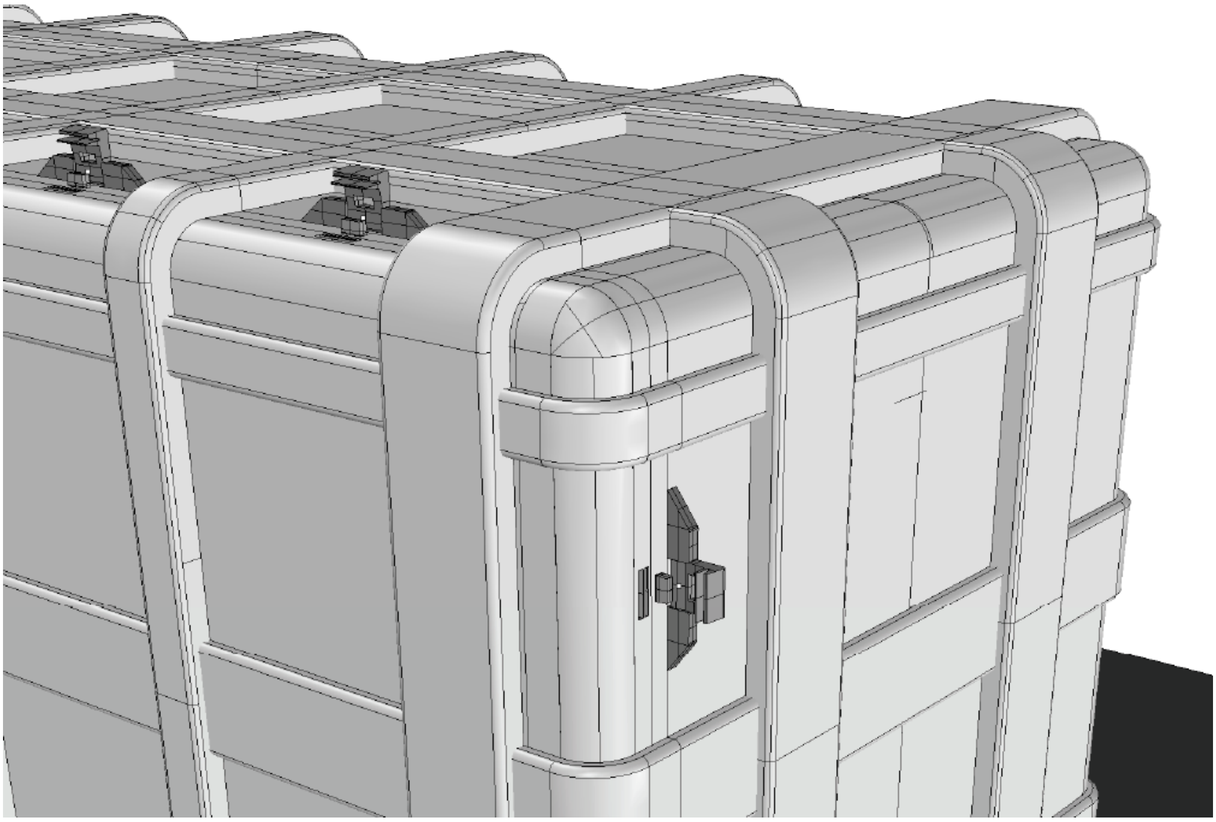

Figure 22 - Details on locking system

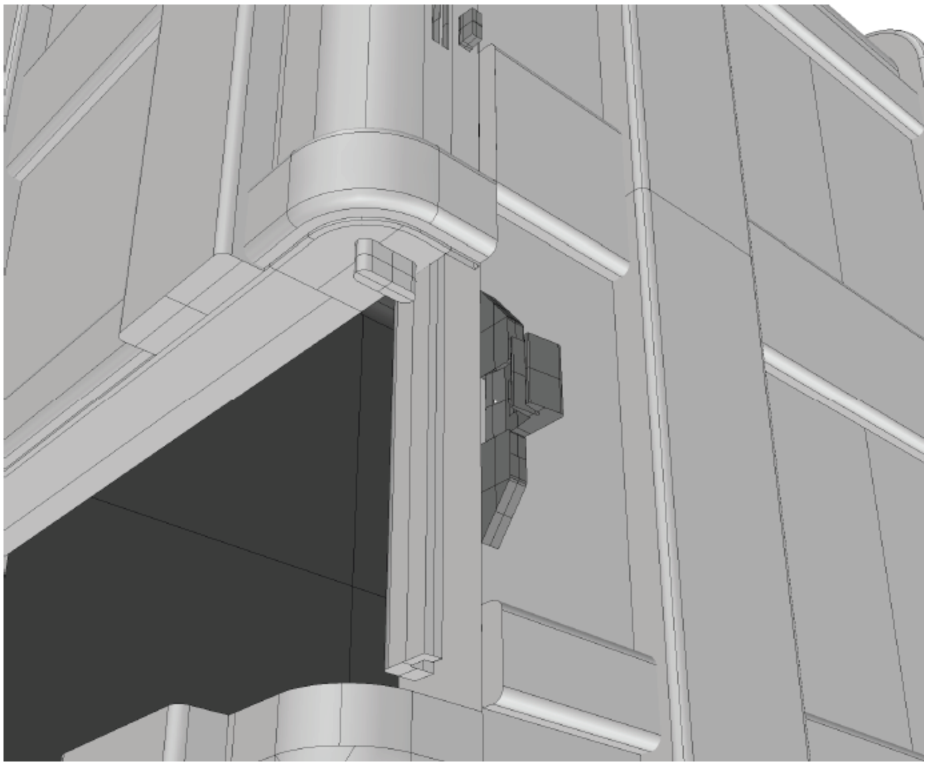

Figure 23 - Locking System