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"Defining Next-Generation Additive Manufacturing Applications for the Ministry of Defence (MoD)"

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Abstract

"Additive Manufacturing" (AM) is an emerging, highly promising and disruptive technology which is catching the attention of the Defence sector due to the versatility it is offering. Through the combination of design freedom, technology compactness and high deposition rates, technology stakeholders can potentially exploit rapid, delocalized and flexible production. Having the capability to produce highly tailored, fully dense, potentially optimized products, on demand and next to the point of use makes this emerging and immature technology a game changer in the "Defence Support Service" (DS2) sector. Furthermore, if the technology is exploited for the Royal Navy, featured with extended and disrupted supply chains, the benefits are very promising. While most of the AM research and efforts are focusing on the manufacturing/process and design opportunities/topology optimization, this paper aims to provide a creative but educated and validated forecast on what AM can do for the Royal Navy in the future. This paper aims to define the most promising next generation Additive Manufacturing applications for the Royal Navy in the 2025 – 2035 decade. A multidisciplinary methodology has been developed to structure this exploratory applied research study. Moreover, different experts of the UK Defence Value Chain have been involved for primary research and for verification/validation purposes. While major concerns have been raised on process/product qualification and current AM capabilities, the results show that there is a strong confidence on the disruptive potential of AM to be applied in front-end of DS2 systems to support "Complex Engineering Systems" in the future. While this paper provides only next-generation AM applications for RN, substantial conceptual development work has to be carried out to define an AM based system which is able to, firstly satisfy the "spares demands" of a platform and secondly is able to perform in critical environments such as at sea.

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Keywords: Additive Manufactruing, Manufacturing Systems, Defence

1. Introduction

This paper represents the results of an exploratory applied research study carried out with Defence Support Services (DS2) providers, Ministry of Defence (MoD), Navy Command Headquarters (NCHQ) and Defence Equipment and Support (DE&S) of the United Kingdom. The aim of the research is to define the most promising next generation "Additive Manufacturing" (AM) applications in the context of the "Royal Navy" (RN) operations and supports. RN platforms are extremely complex entities, featured with a large number of Complex Engineering Systems (CES) and extended or disrupted supply chains. In order to allow the RN's platforms to operate effectively, the DE&S and its industrial partners need to establish "Defence Support Services" systems to provide to the front-end players whatever is required in terms of support. According to [1] AM is an enabler of rapid, delocalised and flexible manufacturing which requires limited space and resources to operate and is able to exploit design

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freedom. Nevertheless, even if AM has a disruptive potential for the RN, current technologies are still not mature enough, are not tailored to the RN applications and requirements and most of all AM technology alone is not the solution to the RN but the core technology of more comprehensive systems. The contribution to knowledge of this paper is given by the definition of future AM applications for the RN, a definition of the problem space faced by the RN, a definition of the opportunities provided by AM to the RN and an exhaustive list of operational aspects of AM. The contribution to methodology is represented by presenting a novel, multidisciplinary and exhaustive approach to technology exploitation and application definition.

2. Research Methodology

The novel and multidisciplinary methodology applied is based on Systems Engineering principles developed by [2] [3] [4] and is outlined in Fig. 1.

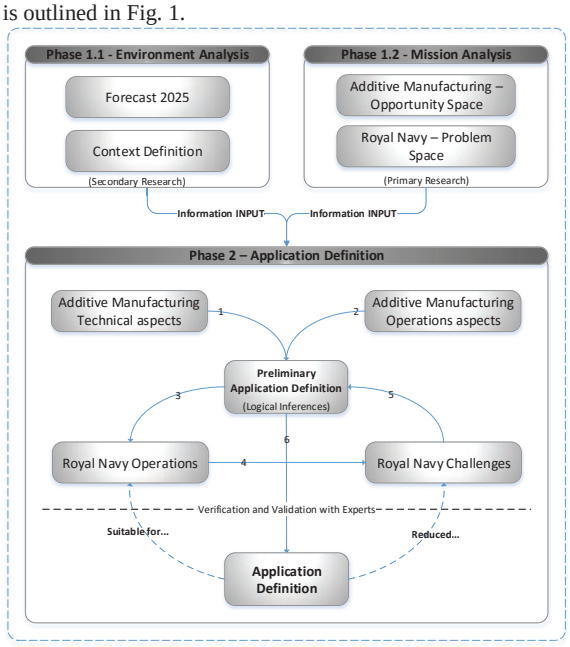

Fig. 1 - Multidisciplinary Methodology

The methodology discerns technical and operations aspects of the technology and combined with macro and micro environment aspects allows to define 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 tailored to RN operations.

In order to feed the "Application Definition" process with reliable information and different perspectives, key experts of the UK Defence Value Chain have been involved. The list of experts is outlined in Table 1:

Table 1 - List of Experts

Organisation	Position	Experience
Navy Command Headquarter (NCHQ)	Commander Royal Navy	30
Support Service provider	Through-Life Support Manager	30
Support Service provider	Operational Support Manager	33
Defence Equipment and Support (DE&S)	Technology Maritime Delivery	30
Defence R&D Firm	Technical Lead	17
Support Service provider	Technology Acquisition Lead	10
Defence R&D Firm	Engineering Manager	10
Research Institute	Researcher	6

The elicitation approach adopted in order to capture the expertise and perform logical inferences to develop conclusions is outlined in Fig. 2.

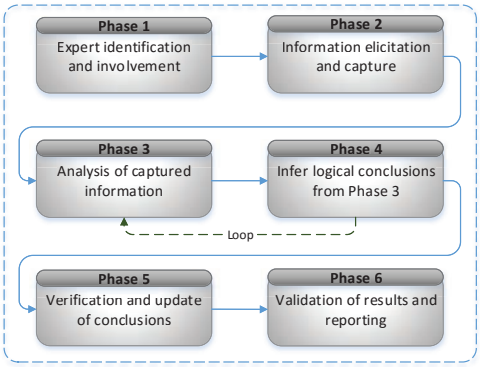

Fig. 2 - Expertise elicitation process

Firstly, organisations of the UK Value Chain have been contacted and requested to nominate an experienced and reliable source of expert. 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.