**21[ST] INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17**
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

# ADDITIVE MANUFACTURING AND THE PRODUCT DEVELOPMENT PROCESS: INSIGHTS FROM THE SPACE INDUSTRY

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## Abstract

With Additive Manufacturing (AM), manufacturing companies have the potential to develop more geometrically and functionally complex products. Design for AM (DfAM) has become an expression implying the need to design differently for the AM process, compared to for conventional, usually "subtractive" manufacturing methods. There is a need to understand how AM will influence the product development process and the possibilities to create innovative designs, from the perspective of the product development engineer. This paper explores the expected influence of AM on the product development process in a space industry context. Space industry is characterized by small-scale production, and is increasingly cost-oriented. There is a general belief that AM could pave the way for more efficient product development. Three companies have been studied through interviews, observations and workshops. Results show that engineers' expected implications of introducing AM in the space industry are: the involvement and influence of customers and politics on innovativeness; the need for process understanding and usage of new tools for DfAM-thinking; the need for qualification of AM processes.

**Keywords**: Design for Additive Manufacturing (DfAM), Design engineering, Design process, Space industry, Product development process

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21[st] International Conference on Engineering Design (ICED17), Vol. 5: Design for X, Design to X, Vancouver, Canada, 21.-25.08.2017.

# 1 INTRODUCTION

The expression "Design for Manufacturing" (DfM) has been a familiar concept in design engineering, and is based on a collection of different manufacturing methods such as milling, drilling or forging (Ulrich and Eppinger, 2012). These conventional methods have either a subtractive or forming manufacturing approach. With the emergence of Additive Manufacturing (AM) approaches, the expression DfM has been further developed into "Design for Additive Manufacturing" (DfAM) (Gibson et al., 2015). Earlier DfM approaches were implemented primarily in the embodiment and detail design phase, while the DfAM approach relates to the whole product development process and is included in all of its phases (Kumke et al. 2016). Many companies within various industries have recognised the advantages of AM technologies, which have the potential to radically change design work in the product development process (Gibson et al., 2015). Studies have shown that, in the case of low production volume or geometrically complex products, use of AM results in a lower price for the final product. This means a considerable potential for increased value of individualised products (Campbell et al., 2013). Product designs can also be optimised in terms of e.g. weight and strength (Gibson et al., 2015). At the same time, this puts design engineers in a new situation in which they may be required to move from their conventional manufacturing thinking to an additive manufacturing thinking (Kumke et al., 2016). This need for a change of mind-set resembles what has already been experienced with the introduction of polymer matrix composite materials. The characteristics of these materials places considerable responsibility on the designer, since choices made early on in the product development process will impact the final material properties and product performance (CMH-17, 2012).

The space industry is characterised by large-scale national and international programmes, financed by state investments for science and technology development (Fortescue et al., 2011). These are affected largely by pan-national political intentions and agreements. Combined with strict requirements in terms of the technological solutions applied (due to the extreme environments), this implies special conditions for engineering work. Large multinational or national space programs are launched (e.g. by ESA or NASA) with huge budgets, but from a space company perspective, the space technology market means competition for the best technological solutions. Combining this with what is, from a technological point of view, irrational political intents and decisions concerning participants (or participating countries), represents a challenge for the development of new technologies in the long-term. At the same time, pressure on ecological footprint reduction, and a constant need for large cost reductions lead to research and development in lighter materials and new development methods (EU, 2016). In this respect, AM is an interesting technological development that is paving the way for radically new design concepts and manufacturing in new materials.

This paper gives an insight into the expectations of AM in terms of the product development process in the space industry from the perspective of engineers in a design team. The study was conducted at three companies that are active in the international space industry, and the results presented here are based on an analysis of data from interviews and workshops.

# 2 CHARACTERISTICS OF PRODUCT DEVELOPMENT IN THE SPACE INDUSTRY

The space industry is a typical capital-intensive industry with high-risk projects, and with development historically influenced by government-run programs. However, new actors (e.g. SpaceX or Blue Origin) are changing the scene, moving the industry towards a commercial marketplace and consequently also greater competition (Fortescue et al., 2011). In order to keep up, the established actors need to ensure that their offerings remain attractive, i.e. providing products at a competitive price. This has increased cost awareness, and reduction in cost is highlighted as the major key driver in new development projects (Brodin et al., 2016). An example of this is the proposal from the French space agency (CNES) to the European Space Agency (ESA) to develop a next-generation rocket engine with a challenging cost target of a 90% cost reduction compared to the current Ariane 5 main-stage engine (SpaceNews, 2016). Unfortunately, the trend is for large development projects (not only space-related) of complex engineering systems to overrun in terms of both cost and schedule (Simpson et al., 2011; Sinha et al., 2016).

Many products in the space industry consist of complex “systems of systems” working together, in which every sub-system contributes to the overall function (e.g. thrust for a rocket engine or earth monitoring for a surveillance satellite). The development of such a system is a large project spanning several years from concept to launch (Fortescue et al., 2011). Managing a task of this kind requires the system responsible (Original Equipment Manufacturer, OEM) to follow the development work, both internally, and externally done by the sub-system suppliers. At the same time, the OEM’s customer expects continuous status updates in order to understand how the project is progressing. Systems engineering is the field of complex systems development (Blanchard and Fabrycky, 2006) and as such, it is highly relevant to the design of space systems. The typical approach in system design is to decompose the requirements of the upper levels in the hierarchy into manageable pieces to be flowed down to lower levels (subsystems) (Crawley et al., 2004). Interfaces are the boundaries that the sub-system designer sees and therefore they need to be well-defined in order to facilitate design work. However, fixed interfaces also limit the freedom of design for the sub-supplier, which is forced to adapt its design to the given interfaces. At the same time, the overall architectures of many systems have been set in the past, and the same system designs have been used since then. For example, rocket engines have had basically the same system design since the 1940s when Werner von Braun designed the V2 rocket. Propellant in the form of a fuel liquid and an oxidizer liquid are still used in rocket engines today (Fortescue et al., 2011). In such cases, new development, or innovation, is pushed out to the sub-systems (Crawley et al., 2004) in order to achieve increased product performance and/or value. This means that the sub-system responsible is forced to find innovative design or technology solutions in order to increase the competitiveness of the system as a whole, while at the same time being hampered by set interfaces and requirements from the OEM.

## 3 ADDITIVE MANUFACTURING IN PRODUCT DEVELOPMENT

Two major issues involved in implementing AM in the product development process are the designer's ability to absorb all the opportunities offered by AM (Campbell et al., 2012), and the designer having knowledge of the numerous limitations in design that these manufacturing processes entail (Thompson et al., 2016). When designing products for the purpose of manufacturing with AM, one of the first choices is whether to re-design an existing model or to design a new one. Klahn et al. (2015) discuss two alternative types of design strategies for AM, the first of which is called the *manufacturing-driven strategy*. The designer retains a conventional design, changes the model slightly and uses AM as a substitute for other manufacturing processes. The other approach, referred to as *the function-driven strategy*, aims to use the full potential of AM and take advantage of the characteristics of AM in order to improve a product's functions (Klahn et al., 2015). Regardless of the chosen approach, there are several opportunities for optimising the final product, such as parts consolidation and improved functionality (Campbell et al., 2012).

A study conducted by Kumke et al. (2016) shows that previous DfAM research lacks integration into a common framework. This means that design engineers are not provided with a methodical AM product development process to guide them from product concept to detailed design. However, even if they suggest a broader AM product development framework (Kumke et al., 2016), many other researchers have realised the limitations of creativity among design engineers, and therefore computational topology optimisations have emerged to assist in design (Leary et al., 2014). Maidin et al. (2012) found that use of an AM design feature database was considered inspirational, useful and helpful during the conceptual design of products, in particular for less-experienced designers. However, it is important for design engineers to understand the design rules (including process capability) in order to ensure manufacturability (Kumke et al., 2016; Thompson et al., 2016).

Within space applications, the rapid manufacturing time, design freedom and high material utilisation (buy-to-fly ratio) are characteristics that are promising with AM. Some typical factors in the space industry that could benefit from using AM are: (i) the industry is characterised by complex products in low volumes, (ii) low weight is essential to ultimately allow for increased payload weight, (iii) optimisation of product design for high (or increased) functionality and novel solutions, (iv) cost-driven products (Gibson et al., 2015). For the space industry, both metal powder bed (PB) and directed energy deposition (DED) with metal powder or wire are of interest (Dordlofva et al., 2016). Whereas PB methods use powdered materials for each layer, and a thermal energy source such as laser or electron beam fuse together the particles with a controlling mechanism, the DED method builds each layer with

either powder or wire simultaneously with the thermal energy source located above the surface (Gibson et al., 2015). These two general approaches have different application areas. DED has a high deposition rate but a low capacity for producing complex geometries and is, therefore, more suitable for larger structures (meters in dimension) with less complexity. PB, on the other hand, is more suitable for the manufacturing of smaller products (decimetres in dimension) with intricate geometries.
Given the recent fast development of metallic AM, there are still challenges with process instability rendering a variation in microstructure and hence mechanical properties of AM parts (Uriondo et al., 2015). It is important to keep in mind what material characteristics that are needed for a specific design (Seifi et al., 2016). In any case, if the AM process can be controlled at a level sufficient for the extreme requirements of the space industry, the possibility of radically changing the product development approach has to be considered.

# 4 RESEARCH METHODOLOGY

To begin with, a literature study was conducted to explore the product development process and the use of AM in a space industry context in which complex product systems are developed. In order to include a broader perspective of how the product development process is used, literature study also included the civil aerospace industry due to its close connection to the space sector. The findings of these literature studies were then used to establish the basis of this paper and to build up the methodology for data-collection.

## 4.1 Gathering empirical data

Three companies from the space industry were included in the study. Company A was studied in order to obtain a deeper understanding of the development work within a company, while Companies B and C were included in order to acquire a broader perspective and to understand the general applicability of the results. In order to fully understand the work approach in product development at Company A, management and guiding documents for the product development process that are available internally were studied and documented. Based on these findings and the literature review, a set of interview questions was drawn up covering two main subjects: (i) *The Product Development Process* and (ii) *Additive Manufacturing*.
Eight semi-structured interviews were conducted at Company A, with respondents chosen from a pool of approximately 60 engineers working with product development in space applications. The respondents were selected based on their experience and seniority (leading engineering roles). In addition to the interviews, three workshops were conducted at Companies A, B and C. These focussed on exploration of expectations and requirements from the companies and their customers if AM were to become feasible in the space industry. All companies are global and the visited sites are all located in Sweden. Table 1 summarises the data-collection approach.

*Table 1. Companies included in the study*

| General description of the companies included in the study | Company | Study of Internal documents | Interview respondents | Workshop participants |
|---|---|---|---|---|
| All three companies operate in the space industry. The companies develop and manufacture complex and high performance products, such as sub-system components for launcher applications and satellites, as well as experimental platforms. | A | Yes | Eight engineers within different roles in the product development organisation, including chief engineer, design leader, design engineer and manufacturing engineer. | Roles from different levels of the company, including department manager, quality manager, design leader, manufacturing engineer and design engineer. |
| | B | No | N/A | Roles from different levels of the company, including department manager, chief engineer and design engineer. |
| | C | No | N/A | Roles from different levels of the company, including company management, subsidiary CEO and design engineer. |

The interviews were conducted by two of the authors. Duration was 45-70 minutes and all interviews were recorded and transcribed. One of the authors has several years of experience in the design of space systems and has a placement as an industrial PhD student at a company in the space industry. Interviews were conducted together with the PhD student among the authors who is new to the space industry. The third author participated in workshops, committee meetings, and company visits. In an attempt to avoid biases in the material, the first analysis of the collected data was conducted by the PhD student not employed at a company, who could take the role of external auditor (as suggested by e.g. Creswell, 2009) throughout the research process. Even unconscious bias could otherwise appear if a person had in-depth knowledge about case data. The advantage of the dynamic of having one "inside" observer, for interpreting e.g. internally used language and expressions, and two "outside" observers, has been used as a way in which to improve the overall validity of the research.

## 4.2 Model of analysis

In designing the interview and workshop guides, the studies were divided into two sections. The first focused on the Product Development process in a Space Industry Context and the second focused on Additive Manufacturing in Space Applications. During the initial analysis of the transcribed interviews, 5 categories were found to be the most commonly-addressed subjects within the first section, and 4 subjects within the second section (Table 2). The interviews were therefore coded according to these categories in order to deepen the analysis, and the workshops were documented and related to the same categories. The steering documents available for the design engineers at Company A were documented and analysed in relation to both previous product development process research and the interviews conducted. Finally, the empirical findings were related to the literature findings in the discussion part of this paper.

*Table 2. The nine categories extracted from the interviews*

| Focus Area | Categories |
|---|---|
| The Product Development Process in a Space Industry Context | Influence of politics and customer involvement |
| | Similarity and difference between space and civil aerospace industry |
| | Shift towards cost |
| | Prototypes |
| | Innovation |
| Additive Manufacturing in Space Applications | The involvement of prototyping in the product development process |
| | Challenges with AM process understanding |
| | Product qualification of AM in the product development process |
| | Reduction in lead-time |

# 5 RESULTS FROM ANALYSIS OF THE EMPIRICAL DATA

This section presents the results from analysis of the empirical data collected in this study. The analysis is divided into *the product development process in a space industry context* and *additive manufacturing in space applications*, with the subsections described in Table 2.

## 5.1 The product development process in a space industry context

The steering documents available for design engineers at Company A show the use of a stage-gate approach in the product development process. The documents are well formulated and every step is clearly described. If an engineer has a specific task, such as design leader, the system also makes clear what gates or tasks this specific person is responsible for. All the respondents in the interviews talked about this system when discussing the product development process at the company, but not all were familiar with each specific task in the stages since they had not worked in all phases.

### *5.1.1 Influence of politics and customer involvement*

According to the ESA structure, most of the financing is obtained from political rather than internal sources, with funding released every third year. This results in short-term goals in order to ensure financing in the next three-year period, which makes it difficult to take major steps in the development process. Since each product is expensive, it is uncertain that the product development projects will get the financing needed for developing a new product. Many of the respondents' report experiencing that it is "space Europe" that determines what kind of technology that will continue to be developed, and this can quickly change due to the short financing time frame (every third year) and different political objectives. This leads to an environment in which the industry feels that they need to not only verify and qualify their products, but also prove their confidence in future technology with limited possibilities for experimentation.

Furthermore, the customer is considered by the respondents to be involved in almost every step of the product development process, with the project driven by an iterative cooperation. Requirements and guidelines from the customer are received early on in the project, with consideration given to the complete product system. The respondents' experiences are that apart from the internal requirements set by steering documents, the product development is also heavily influenced by the customer requirements. As system responsible, the customer has control over the product development, which leads to late changes to requirements, potentially leading to unexpected work. Since both costumer and internal reviews occur, it can lead to double gates. Some of the respondents found that they spent most of their time either preparing for, or attending, a review. This leads to the feeling of not having enough time to be creative and to utilise the full capability of the design engineers at the company. However, the respondents acknowledged that this customer involvement is also positive since it brings a certain structure and requirement in terms of documentation.

#### *5.1.2 Similarity and difference between space and civil aerospace industry*

Since Company A performs product development in both the space and civil aerospace industries, discussions of similarities and differences in the work approach occurred naturally. Product development projects within civil aerospace also have a strong customer involvement, just as with space, and in the same way, the high requirements from both the company and the customer sometimes collide. However, projects in the space sector generally have a longer lead-time than within civil aerospace, where the customer often gives a distinct deadline within 1-2 years. Today, development within space can last for up to 10-15 years. This was attributed partly to political involvement and the need for demonstration of technology by means of extensive testing. In civil aerospace, there are more opportunities for testing a part on a flying test bed, whereas space products do not have the same opportunities. Another major difference between the two development streams is the expected volume of the final product, with space products manufactured in tens of parts per year compared to several hundred within civil aerospace.

#### *5.1.3 Shift towards cost*

There is an experience of having both political and customer requirements steering the project towards a less costly final product. Some of the respondents talk about the goal of Ariane 6 being less expensive than Ariane 5, and they experience the iterative collaboration with the customer as positive since they have the opportunity to discuss production and cost. The final product needs to be manufactured efficiently, as that would result in a less costly final product. Since the space industry mainly manufactures parts at a low-volume production scale, it would be beneficial to avoid expensive investments such as castings. The respondents also discussed the fact that lighter products and less expensive materials could also lead to a lower final product cost. There is a general feeling of having newer, private initiatives pushing and challenging the industry towards faster developments and less costly products. The respondents expressed a feeling of having both the customer and other design engineers believing that AM can contribute to these aspects.

#### *5.1.4 Prototypes*

There was a large spread in the experience of prototypes, with some respondents reporting having worked with them on some projects, while other respondents claimed never to have encountered them. However, many of the respondents were somewhat unsure on how they should describe a prototype, with most providing several different descriptions. These included the prototype being built for testing an idea or to learn something, and descriptions of having prototypes mainly for testing the manufacturing processes. Some of the respondents reported feeling that more extensive use of prototypes would help the product development. One respondent talked about having difficulty thinking in 3D while designing in a CAD tool, and there were experiences of ideas that did not work in the end and ultimately proved costly. It was believed that greater use of prototypes would help design engineers to get a sense of the part and to understand whether the concept was feasible.

#### *5.1.5 Innovation*

Many of the respondents reported not feeling innovative when working with product development for space applications. They discussed the strategy of re-using previous designs, with most believing that this hindered opportunity for innovation, while others thought that they did not re-use old designs enough. Most of them talked about mainly having an incremental development approach, with some feeling secure in such an environment. A small number of respondents expressed a feeling that this restraint is slowly resolving due to the new focus on cost. Capability in the production system was something that most of the respondents felt to be part of the restriction on design. There was a generally expressed feeling of wanting to work without the limits of some of the manufacturing processes, such as casting. Some of the respondents expressed a need for more demonstrator projects, as they want most of the risks eliminated before product development with the customer for a shorter development time. Since space products have high requirements, the possibility to create radical solutions are affected and even though the design engineers expressed a desire to be more innovative, they felt that they did not have the margin within project budgets to challenge conventional designs.

### 5.2 Additive Manufacturing in space applications

According to the respondents, some aspects need to be considered in order to successfully implement AM into the product development process. Besides the obvious geometrical benefits, with respondents being positive to the new complex geometries now available, they also apparently realise the advantages of e.g. material transitions or new material compositions. One respondent discussed the possibility or ordering a powder material alloy according to the mechanical properties needed, which was a typical feeling of what AM could bring in the future. However, the discussions concerning the work approach involved prototyping, process understanding, machine availability and product qualification. The findings presented here are mainly from the interviews, but the outcome from the workshops is also included in order to relate the expectations of AM from different company perspectives.

#### *5.2.1 The involvement of rapid prototyping in the product development process*

Most of the respondents expressed a belief in the use of AM in the concept development phase, with the opportunity of making quick design alterations. They showed considerable interest in the ability to change the CAD-model slightly and easily print it out for evaluation. Because they have had some situations in which ideas and models have not been as successful as predicted, they feel some hope that part of this uncertainty will be eliminated with an iterative AM prototyping development process. They talked about their current work of evaluating AM in some of their products, with some of the respondents expressing the importance of understanding whether the process ultimately gives added value to the product.

Since many of the respondents expressed an opinion that AM brings with it a new mind-set in order to benefit from the degree of freedom, they feel that they need help with new design tools and design systems that are not currently available at the company. A lot of the early work today is done in 1D or 2D, and the thought of a shift towards 3D-thinking with prototypes was encouraging. One respondent, however, acknowledged that this would probably also imply more extensive use of 3D calculations (FEM and CFD) even in the early phases. Many of the respondents felt that AM would allow them to work with several concepts simultaneously, and the ability to use physical models to evaluate concepts relative to each other seemed to be a driving force. According to the respondents, these physical models could be made from metals cheaper than those used in the final product, or in some cases from polymer materials. These models are supposed to help designers to evaluate concepts and to take the next steps faster than would be the case for product development without rapid prototyping. One respondent talked about the possibility of more component-testing if parts could be printed in the intended material, instead of waiting for expensive castings. There was a general belief in all companies included in the workshops that use of AM in prototyping would help them not only to understand the AM process, but also increase their iterations during the design process.

#### 5.2.2 Challenges with additive manufacturing process understanding

Most of the respondents discussed the feeling of AM being the latest new trend within the industry. One respondent talked about the phenomena of belief in AM being similar to the trend of composites that took off within the company about 10 years ago. Many of the respondents expressed considerable belief in the new manufacturing method, but most of them also understood that there are limitations in the process that are not fully understood yet. This is something that caused general uncertainty regarding how to include the manufacturing process in product development in order to fully utilise it. They requested a new design method in order for design engineers to understand the process, and design tools that could help them to know where the limits were. Some of them also discussed the need for training and having an expert explain the opportunities and limitations inherent in the process. One respondent expressed the feeling that most of the work done on AM within the company involves developing the manufacturing process, with little attention paid to learning how to design for AM. Some of the respondents expressed a need for machines in-house in order to learn how to use the process. While they are currently experimenting with AM, they are dependent on external manufacturers or colleagues at another site for help learning about the process. This leads to the feeling of not being able to learn the process fully. There was slight concern about the need for complementary processes in order e.g. to improve the surface finish, which also leads to some discussion as to whether AM brings greater value to the final product. These discussions also featured prominently in the workshops. The participants talked about the need for general training in process understanding for their design engineers in order to keep the manufacturing process in mind while designing.

#### 5.2.3 Product qualification of additive manufacturing in the product development process

Every respondent raised the issue of having the product qualified for flight, with the space industry generally having strict demands for mission-critical parts. One respondent referred to the qualification of a product being complete after the first flight. These strict requirements for products to be developed and used in space applications are the reason why demonstration of technology is required. The aim is to include technologies matured to a certain level (TRL6) in product development, while demonstrators are used for lower levels of development. There was a general concern about the familiar problem (e.g. Seifi et al., 2016) of machine instability and variation in material properties, which made them realise that there is a great need to involve product qualification early on in the product development process. The need for a methodology for qualifying individual parts was expressed, in order to ensure success of the print. Two other concerns regarding product qualification were the quality of the powder and whether implementation of product qualification would entail new limitations in terms of the design possibilities. These issues were raised by all the companies during the workshops as the main reason for caution on the part of both the companies and their customers in having AM implemented into their manufacturing choices.

#### 5.2.4 Reduction in lead-time

Most of the respondents discussed the significant potential for AM to shorten their lead times. However, one respondent added that the development work itself is time-consuming, and shortening the lead-time required not only part production to be shortened, but also efficiency-improvement in design work. One respondent had heard about a company that saved 60% in lead time while implementing AM and another talked about having 1.5 years of waiting for casting while AM only took a couple of months. Because the lead time for casting is so long, projects are often forced to order them long before the design is set, resulting in more material being used in the design as a margin. There was a general feeling that AM eliminates this problem. However, one respondent did express the concern of having design engineers postponing some of the details to later on in product development because they “have more time” with AM. This could ultimately lead to details of the design not being finished towards the end of the product development work.

## 6 CONCLUDING DISCUSSION

The product development process in the space industry is strongly influenced by both politics and customers, which makes the development more complex compared to e.g. civil aerospace. However, workshops indicated that the level of politics involved can also vary in the space industry, depending on the customer, whereas with commercial customers there is usually less politics and more aggressive product development. Our study indicates that the space industry adopts a stage-gate approach (Ulrich and Eppinger, 2012) due to the importance of verifying the quality of the product throughout its development. Despite a strong connection to the customer and use of an iterative work approach with the customer, many of the respondents felt that this put too much emphasis on reviews instead of development work. Together with the feeling of not having sufficient financing or time for product development, this made them feel that they were not making the most of their potential for innovation. However, the feeling of not being sufficiently innovative was not something that the respondents seemed to care about very much in their daily work due to the importance of safe and qualified products. Thus, one of the major expectations of AM was the ability to create new, complex and innovative products that could help the company to deliver quality products to their customers. This was also suggested by the results of the workshops: that there was a willingness to use AM as a bridge towards new, radical solutions. However, some of the respondents expressed the sense of security in having an already proven design to lean on, hence using an incremental product development process. These discussions related to the uncertainty of financing and not knowing whether the project would be allowed more time for completion.

Our study indicates that there is a great willingness to learn how the AM process works and how to design for AM, but there is a feeling of not having enough resources for this experimentation. An initial general suggestion for design engineer teams in a space industry context is to gain as great understanding of the process as possible and to ensure that there is access to machines. Availability of machines seems to promote process understanding and confidence in the process, thus creating substantial opportunities for creating innovative products that can not only reduce cost but also increase functionality and/or value. Another suggestion that was put forward in both the interviews and the workshops was the need for opportunities for training, with an expert teaching design engineers about both process understanding and general AM thinking. A third suggestion that was broadly discussed, again both in the interviews and the workshops, was the use of prototypes in the product development process. It is generally thought that rapid prototyping would help not only to acquire a limited process understanding, but also an understanding of how the model and idea are actually feasible. Some of the respondents displayed some doubt concerning their ability to understand 3D from either a 2D drawing or a virtual 3D model, and that increased use of prototypes could help. This, together with the feeling of having a fast and iterative product development with AM machines early on in the project, created some certainty amongst the respondents that their future space products would have an opportunity to evolve and radically change.

Among the interview respondents and workshop participants, there is a general belief in AM and all the opportunities it enables, but there was also an awareness of the maturity level of the processes. All the respondents brought up the issue of qualifying the product throughout the entire product development process. This included material properties, powder quality and part accuracy. In order for customers, management and the design engineers themselves to fully adopt AM into the product development process, there is a great need for a systematic and reliable qualification process.

Of the nine categories identified in the analysis of the data, it can be concluded that the most important expected implications of introducing AM into the product development process for space applications are as follows:

- AM is believed to entail a potential for innovation, however, this potential is affected by the way in which the general product development process is set up (e.g. gates from both company and customer) and the extent to which financing can be guaranteed in the long-term from a political perspective.
- New tools and methods are needed to aid the design engineer design in 3D. Prototypes, software and tuition are requested aids and recommended by the authors.
- Human aspects need to be considered (e.g. having an already proven design to lean on, fear of the process, machine availability, initial prototypes).
- The need for qualification is evident – not only in terms of the processes and products manufactured using AM, but also in terms of the engineers working with the processes and products, i.e. understanding AM.

This study was limited to eight interviews with design engineers at one company, and workshops with two additional companies, all of which develop products for space applications. The respondents and workshop participants had limited experience of using AM. The interview respondents and workshop participants had limited experience in using AM, and therefore, this study should be seen as a guidance for in what direction a future extended study should be focused. More extended interview rounds should be conducted at more than one company and in industries other than space, and preferably with respondents with varying experience of AM.

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