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Possible Applications of Metal Additive Manufacturing in Aerospace Vaporizers

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ABSTRACT

Many aerospace components are complex, they must meet challenging requirements, and require extensive fabrication processes. For vaporizer systems such as resistojets or heat pipes, their internal chambers and duct work have meant they are difficult to fabricate and also not fully optimized. Metal additive manufacturing methods offer a solution to these complex production challenges. In this work, current methods of metal additive manufacturing are evaluated for possible use in producing vaporizer systems, namely resistojets. Material compatibility, cost, and feasibility are considered to suggest which method should be employed. After evaluating several methods of metal additive manufacturing, selective laser melting (SLM) was chosen as the most promising for resistojet development. SLM is readily available from numerous companies for on-demand part printing. SLM also has a sizable catalog of materials that can be used. For resistojets, the most important evaluation factors are strength, maximum operating temperature, and the ability to form and sustain thin-walled structures. Two materials were selected for use in SLM: a cobalt–chrome alloy, Co-28Cr-6Mo, and nickel alloy, Inconel 718. Two different resistojet design concepts were evaluated. One was a single-component heat chamber and nozzle made entirely of the cobalt–chrome alloy, the other was a cobalt–chrome heat chamber welded to an Inconel 718 nozzle. These two design concepts are the basis for future work on model development, procurement, and evaluation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

Introduction

Resistojet technology has been around since the 1960s. In a resistojet, a heating chamber vaporizes and superheats a liquid fuel that is then exhausted through a nozzle to produce thrust. Once in space, resistojets can maneuver a satellite into a specific orbit and help it maintain that orbit. This technology has grown in use, particularly since the early 2000s, and will continue to grow as space exploration accelerates and the number of satellites on orbit increases. With this growth, there is a need for cost reduction and efficiency in the production of satellite components such as resistojets, as well as a need for their increased performance. An emerging, innovative method to design and fabricate resistojets is by metal additive manufacturing (AM) processes. AM enables more complex geometries while decreasing production costs, and the parts can be manufactured with a level of structural stability comparable to traditional methods. More exploration of these AM design and production methods will enable improved resistojet designs with increased performance.

This work collects knowledge on the current methods of metal AM and recommends methods that are potential candidates for resistojet production. Alongside method selection, materials from which to fabricate resistojets is also investigated and recommended. The selection process considers cost, functionality, and availability, among other factors. While this work is based on an analysis of the available literature, future work would allow for action in the selected method and material. This work demonstrates not only the possibility to integrate AM into a rapidly emerging technology, it lays the groundwork for future proposals and development.

Overview of Thesis

This thesis is organized as follows. Chapter 2 provides an overview of metal additive manufacturing methods. These methods are broken down into classes and then into members of these classes. Chapter 3 looks at the past and current uses of vaporizers in the aerospace industry, including designs of resistojets. Chapter 4 addresses the current usage of metal additive manufacturing within the aerospace industry. Chapter 5 suggests a printing method and material to be used in future resistojet prototypes. Chapter 6 suggest future work in the additive manufacturing of resistojets and vaporizers.

Chapter 2

Metal Additive Manufacturing Methods

Powder-Bed Fusion

Powder-bed fusion (**PBF**) is a laser-based method of AM with metals [1]. PBF is one of the most common and established methods. The basic process begins by establishing a thin layer of powder on a build plate. The machine then melts the powder into a cross section of the part [2]. The build plate is incrementally lowered and new powder layer is formed, a process repeated to complete the entire part. The layers are fused together as the part is being made, and the finished part is cut away from the build plate after production. A schematic of the PBF process is shown in Figure 1. This process yields a high cooling rate for the completed part and better surface finish than most other common methods.

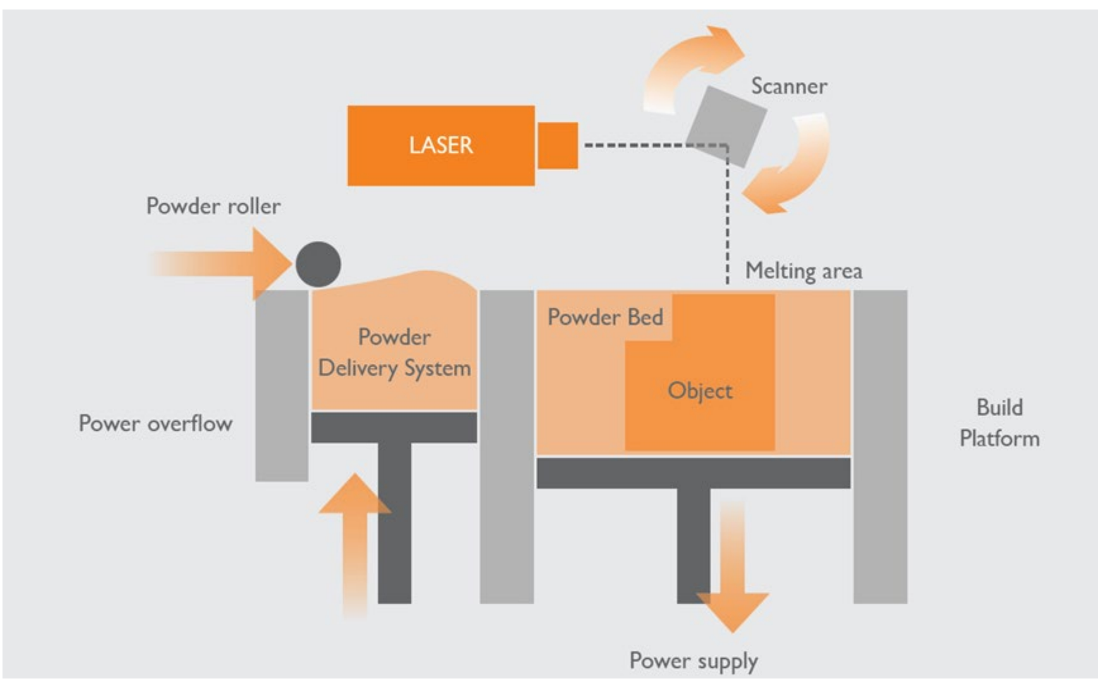

Figure 1: PBF manufacturing process [3]

The rapid development of PBF is due to its benefits, which include the ability to fabricate a large range of geometries with a large range of materials, equal or better properties than some forged metal, and the ability to treat the AM parts in a manner similar to traditional parts. The main drawbacks of PBF are the cost of materials and machinery, the physical part attachment to the build plate, and the metal powder processing and safety measures required. The build size for some PBF machines is limited, but the technology is prominent enough to see continuous improvement [4]. PBF can be split into three main subsets: direct metal laser sintering, selective laser melting, and electron beam melting. Each of these methods differs slightly from each other and offers a different set of benefits.

Direct Metal Laser Sintering

Direct Metal Laser Sintering, or **DLMS,** is a method of 3D printing that utilizes a sintering process. DLMS was one of the first metal printing processes created as it is a derivative of selective laser sintering, **SLS**. The sintering process functions at a lower temperature than melting, thus using less energy; however, this discrepancy in temperatures causes a slight difference in the molecular structure of the parts. A melted part comes out with more cohesive internal structure, as shown in Figure 2. DLMS does not fully liquify the metals and, therefore, works better with alloyed metals than pure metals. Parts manufactured by DLMS can be machined like any part produced by traditional methods, and at times come out with a higher finish quality than an expensive casting process [5].

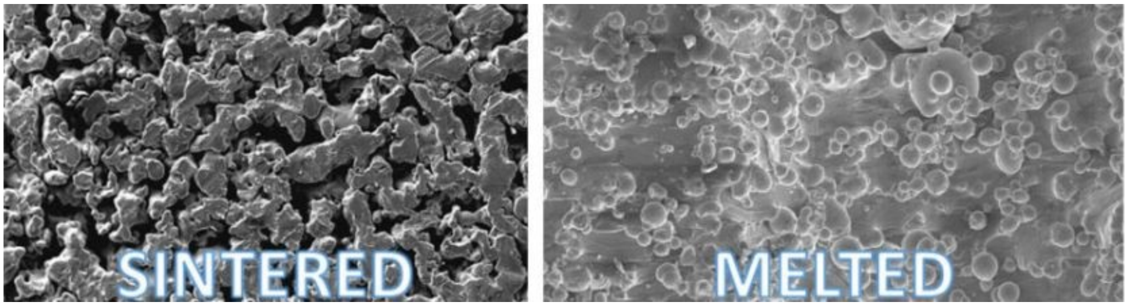

Figure 2: Sintered metal versus melted metal part structure [5]

The advantages of DLMS include a wide selection of materials, the ability to produce reliably strong parts, and powder recyclability. DLMS also has the advantage of being able to create free-hanging structures. Most parts produced through printing methods require support structures; however, DLMS does not require support structures. DLMS is limited in its build size, porosity when compared to true melted parts, and cost of production [6]. This method of production has been previously used in aerospace applications from commercial aircraft parts to rocket exhausts. DLMS provides a wide base of materials at a low energy use but is relatively high cost.

Selective Laser Melting

Selective Laser Melting, **SLM**, is very similar to DLMS as a production process. SLM is a melting process, meaning it functions at higher temperatures than the sintering process, but it produces parts that have a more cohesive molecular structure, as shown in Figure 2. Like DLMS, SLM can be used with a wide range of materials. SLM is a strong contender when there is a need to produce parts with internal structures that are nearly impossible to fabricate with other methods. However, SLM has some disadvantages when it comes to post processing, as the SLM process requires support structures to be removed and finishing processes to be applied [7]. The primary usage for SLM within the aerospace industry is to produce parts that have complex interior structures like ducts. Hence, SLM may be a good fit to produce vaporizers.

Electron Beam Melting

Electron Beam Melting, **EBM**, differs from other methods of PBF in that it uses a high-powered electron beam to melt the powder, as opposed to a laser. EBM is mainly utilized to produce parts from alloys that require higher temperatures than what SLM or DLMS can produce. Currently, GE Additive dominates the market for EBM machines and their set-up and usage costs can be > US$1 millon. GE uses this process to produce parts like turbine blades with a much lower weight than traditional methods [8]. While EBM parts can be less precise than those made with other PBF methods, the build size can be much larger for a nominal change in costs and constraints. The electron beam can reach deeper into the material, causing the powder to melt together better than with other PBF methods. EBM by GE also allows for sintered supports that can be easily removed during post processing [9]. EBM is a promising innovation in the PBF family.

Direct Energy Deposition

Direct Energy Deposition, **DED**, describes an alternative class of manufacturing to PBF. In DED, a beam of energy is used to melt material as it is being extruded through a nozzle. The nozzle has a spool or some other supply of material that navigates through the structure of the part being built. This material is melted immediately, and this process runs until the part is complete. Figure 3 shows a schematic of a common DED process. This manufacturing process can use a wide variety of materials, making it versatile. For the most part, DED is used for repair work but has the ability to produce parts from scratch [11]. The DED class of manufacturing includes Laser Material Deposition, Electron Beam Additive Manufacturing, and Laser Engineered Net Shaping.

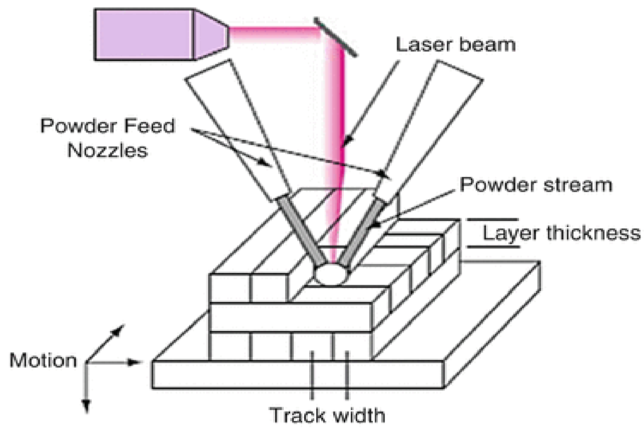

Figure 3: DED manufacturing process [10]

Laser Material Deposition

Laser Material Deposition, commonly referred to as **LMD**, is a branch of DED that uses a laser to form parts by rapidly melting material from a powder extrusion nozzle. LMD has much in common with SLM, as it melts a powder with a directed laser. The difference with LMD is that the print head extrudes the material into place along with the laser movement. This difference is especially useful in repairs of parts that have already been created. LMD can be used to replace methods of repair like Tungsten Inert Gas (**TIG**) welding, as it yields higher control at a lower applied heat [12]. Laser material deposition has been used throughout the aerospace industry to repair turbine blades and other components. Build sizes can be around a meter in length per axis, which is quite large for AM methods [13]. LMD is an exciting prospect considering its material availability and build sizes.

Electron Beam Additive Manufacturing

Electron Beam Additive Manufacturing (**EBAM**) differs from LMD in its material supply method, in that EBAM uses a wire material supply instead of powder. This wire supply is available in most weldable alloys or metals. Some machine manufacturers offer a dual-feed system for the creation of alloys and custom mixtures of materials [14]. EBAM can print very large sizes, up to five meters per axis on some machines, at very high speeds. However, this large build size paired with high production speed results in decreased precision and accuracy of more intricate parts. For large, relatively simple parts, EBAM is the best method. To produce vaporizers, EBAM could be too costly without the necessary precision.

Laser Engineered Net Shaping

Laser Engineered Net Shaping, commonly referred to as **LENS**, is very similar to both EBAM and LMD. LENS commonly takes place in an argon-filled chamber, which provides a low oxygen level to stop oxidation of the materials [15]. Developed by Optomec, LENS is their own take on the DED manufacturing method. LENS has advantages as an in-plant system of production as Optomec designed this process to be compatible with traditional subtractive machining [16]. LENS could be a possibility if DED is the best method of production for a vaporizer.

Metal Binder Jetting

Metal binder jetting is the printing of metal in a process similar to a household inkjet printer. First, the printer deposits powder of whatever material is being used. Then the inkjet arm applies a binding agent to the powder. This process is repeated until the part is completed. Metal binder jetting was originally developed at the Massachusetts Institute of Technology and is now in the marketplace with ExOne, predominantly [17]. Binder jetting is one of the fastest methods of printing due to its design heritage from a basic printer. It also requires minimal heat or support structures and can produce parts at a high volume. In the case of pure manufacturing of parts in which iteration is key, binder jetting has solid footing. In the case of one-off pieces, binder jetting lacks the precision for tolerances to compete with most methods.

Chapter 3

Resistojets, Steam Generators, and Other Aerospace Vaporizers

Vaporizers are required in many aerospace applications. They are used to vaporize water for cooling and fuel in propulsion devices, among other uses. Vaporizers come in many forms, such as heat pipes and vapor chambers for resistojets. A simple diagram of a vapor chamber is shown in Figure 4. The manufacturing process for these devices is complicated and requires metals to be bent into intricately angled tubes, something that is costly and error-prone. The fabrication of this technology has just begun to consider AM. The benefits of metal AM are numerous, but a large part of its increased prominence is the ability to print parts that are otherwise difficult to make. This applies directly to vaporizers, especially in the case of complex internal structures of a resistojet.

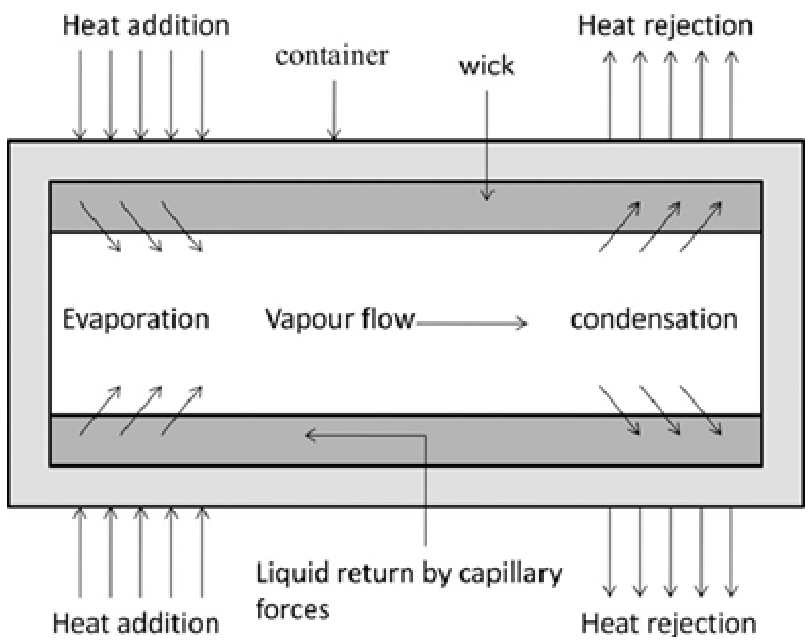

Figure 4: Diagram of vapor chamber [18]

In a paper from the late 1970s, Sherwood describes a resistojet for space propulsion [19], a propulsion technology not widely used at that time. A basic schematic of how a resistojet works is shown in Figure 5. Their resistojet design involved the use of rhenium components that were then electron-beam welded together. Rhenium is a rare element and should be handled with care as there is little known about its effect on humans after direct contact. Sherwood points out that, for their required values of high temperature creep strength and sublimation rate, the only two elements that are compatible with hydrogen are rhenium and tungsten. Rhenium was selected due to its ability to be welded. The rhenium components are susceptible to oxidation at temperatures above 600–700 K and required multiple annealing steps. The thin walls posed the largest challenge and drove the need for the advanced welding process. The other manufacturing methods employed in the fabrication of the resistojet were rolling sheets that were subsequently welded together and chemical vapor deposition (CVD), which takes a gaseous mixture that reacts with rhenium to deposit layers to form a given shape. Three methods of manufacturing—pressing and rolling sheets of rhenium and chemical vapor deposition—were used to make parts out of rhenium and these parts were joined through electron beam welding. Sherwood shows that the key components of a resistojet not only can be made of rhenium, but that they can be combined as well.

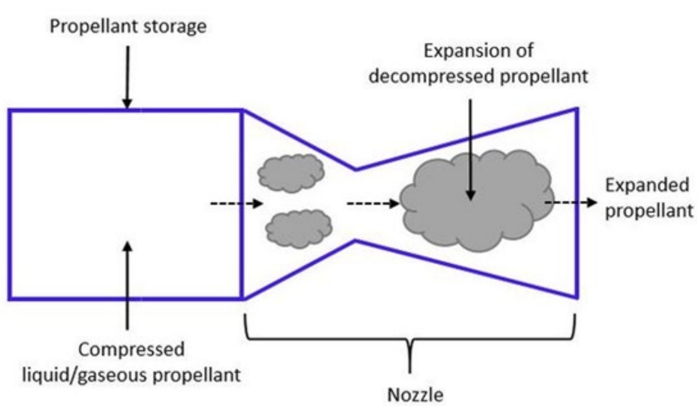

Figure 5: Diagram of basic resistojet [20]

Another material considered for fabrication of resistojets was platinum, as it has a low reactivity with typical propellants, which allows for a long operational lifetime. Platinum was proposed by Louviere et al. [21] during their work on resistojets for a space platform predecessor to the International Space Station. Their resistojet design was to utilize steam, created by heating water inside of a chamber. The design of this heating chamber resembles a heat pipe, and receives the fluid from a filter, ejecting it out of a nozzle for propulsion. This steam generator was designed to utilize waste heat from the platform to heat the liquid water into steam. Integrating such a boiler raises the efficiency of the resistojet while also simplifying its production. Their project was never implemented but has interesting applications when exploring resistojets.

Another notable vaporizer design was developed by Morren [22], who describes a heater element that was manufactured out of a nickel–chromium alloy and integrated a chromel–alumel thermocouple. The heat-exchanger bed was packed with granular silica (sand) with a maximum grain size of approximately 0.8 mm, which helped reduce the two-phase flow field caused by gravitational effects. The heat exchanger itself was made of copper and filled with sand. The water entered the system in a liquid state, encountered a pressure drop, and then was heated until vaporization occurred. This model of a forced-flow, once-through vaporizer was tested and evaluated. When tested in an environment with gravity similar to that in orbit, this vaporizer model held steady temperatures and mass flow rates. The use of copper proved to be a fruitful selection, as copper has a high electrical conductivity.

The use of AM for resistojet fabrication was recently introduced by a research team at the University of Tokyo [23]. Their design reduces the amount of energy that needs to go into heating the fuel. Fuel droplets stick to the walls of a labyrinth-style structure and become vaporized through a pulsating method. This pulsation separates the vapor from the liquid with minimal decrease in specific impulse. The vaporization chamber was manufactured using metal 3D printing of aluminum. The use of AM allowed the team to fabricate the vaporizing cavity and labyrinth structures. The system uses the heat from a communications device to assist the vaporization chamber (and simultaneously cooling the communications device). The system showed a regulated cycle as it was tested, and no water or ice escaped. For their design, aluminum was a viable material that could be printed into complex internal structures.

Resistojets have been used for satellite propulsion for upwards of 40 years now and have been in development from as early as 1965 [24]. Resistojet technology has been considered for Space Station applications. The technology is in heavy usage, yet their production methods are still costly and incredibly complex. This lack of production options opens the door for AM. It is also worth noting that the complex inner structures and channels of a vaporizer for a resistojet take advantage of the unique capabilities of several metal 3D-printing methods. To 3D print a working resistojet, a viable production method and material must be selected.

Chapter 4

Aerospace Applications of Additive Manufacturing Methods

Additive manufacturing with metal has been utilized within and driven by the aerospace industry from the start. Over its century of existence, the aerospace industry is constantly evolving, requiring rapid prototyping, cost reductions, and innovations to improve and survive. AM can meet these requirements, while also producing parts that are the same of better quality level. At its maximum potential, AM can produce parts that are huge improvements over current solutions. Tesla, BAE Systems, Rolls-Royce, and Bell are some of the companies currently producing components of their aerospace systems via metal AM. NASA has produced components for use in their rocket program through copper SLM printing [25].

Sustainability consideration for metal AM in the aerospace world is a very new concern. Joshi and Sheikh investigated how AM could be applied in the aerospace industry, and what the effects would be. Their findings were astounding. The potential reduction in production costs could cumulatively reach US$50 billion by 2025 in the U.S. alone. Their research also outlines materials that have been used in aerospace applications like nickel- and titanium-based alloys. The SLM process reacts differently with a specific titanium alloy, Ti-6Al-4V, and produces a part that comes out with higher yield and ultimate tensile strengths than traditional methods, as shown in Table 1 [26]. Another material, Inconel 718, has a yield strength of around 580 MPa, which is 100 MPa higher than an as-cast version when printed with SLM. This same Inconel also has an ultimate tensile strength of 910 MPa, which is almost 125 MPa above the as-cast version [27].

Table 1: Mechanical properties of Ti-6Al-4V from different processing methods [26]

Manufacturing Process		Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
Additive Process	EBM	830	915
	SLM	990	1095
Other Process	Annealed (Wrought)	790	897
	ISO 5832-3	>780	>860

Turbine blades are currently the most common aerospace component being produced with metal AM. Turbine blades have complex geometry and can be extremely difficult to machine. A team of Russian researchers showed that AM methods are effective at producing turbine blades, with Figure 6 showing one fabricated with their SLM process [28]. GE Aviation, in partnership with Avio Aero, both produces and repairs turbine blades with metal AM. Their largest engine, GE9X has AM turbine blades that were produced in Italy [29]. They have had so much success with this production method that they invested a majority stake into Arcam, an AM company, and created their own additive division, GE Additive, which is projected to be a major player in the multi-billion dollar AM industry. Bi and Gasser [30] showed that the knife-edge of a turbine blade can be repaired using a laser-aided version of metal printing. Their findings showed that using AM to repair turbine blades was successful and should be further explored as a full-scale repair option.

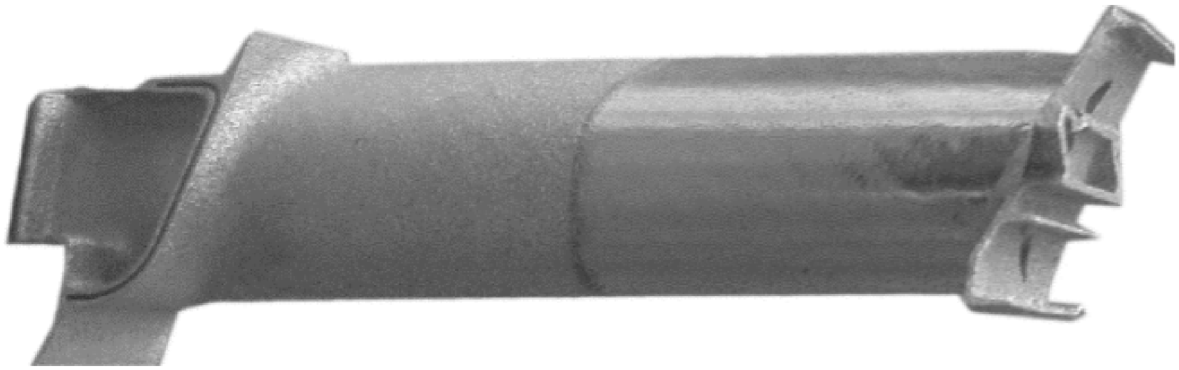

Figure 6: Low-pressure turbine blade produced with SLM [27]

AM has also been explored for fabrication of resistojets and vaporizers. SLM was used to manufacture a modern resistojet [31]. This team used 316L stainless steel for experimental purposes but found that nickel-based Inconel alloys would have been more ideal. Their findings showed that there is promise in using SLM; however, their parts were not accurate enough to be used directly. Considering this was a first-build attempt, the results were promising at 99.7% accuracy when compared to their part model. Multiple iterations of design to work around some of the support flaws and tough spots for SLM could yield a part that is functional.

Metal AM already has deep roots within the aerospace industry. It is just entering the experimental phase in resistojet production. Resistojet parts have been created through SLM and have a high build accuracy and small problems that can be fixed with iterative design work. A material more suited to the actual function of a resistojet should be selected and tested through SLM for certainty that a solution can be reached through this production method.

Chapter 5

Method and Material Selection

Resistojet manufacturing can be completed with metal AM methods for some materials. For this conceptual fabrication methodology, AM with a single metal material is evaluated to produce a single component, i.e., water-fueled resistojet.

Selecting a method of production is based on evaluating criteria such as cost, availability, and effectiveness. Cost savings in fabrication can enable companies to allocate these savings towards technological advancements and component improvement, or to more competitively price their products. Cost is also indirectly related to availability because costs generally decrease as availability increases, and the quality and functionality of fabricated parts increases. Iterating a process is needed to develop it and these improvements are reflected in the resulting part.

The PBF and DED printing methods have a number of machine venders and also a number of printing services available. Of the variants within these printing methods, SLM is the most common method used within the aerospace industry and also has been used previously for fabricating resistojets. SLM is available as an on-demand piece-by-piece production method from multiple companies. Stratasys, SLM Solutions, Forecast 3D, and Craftcloud by All3DP offer this printing service at a relatively low price point. A local State College, PA company, Xact Metal, uses a SLM style printer; however, they do not print in reactive metals needed for true resistojet applications.

Stratasys offers SLM printing for a wide variety of materials. Using common resistojet sizing and sizing from the STAR resistojet project [31] to estimate a build size of a 50 mm diameter, 100 mm length cylinder, SLM costs around US$1500–2500 when using materials that have the required characteristics for resistojets [32]. SLM can utilize a wide range of materials, at a lower cost than some of the less common methods of printing. Other studies have shown that SLM is a good method to use when producing resistojets and other thin-walled pieces. SLM is effective in this case and is readily available from a number of companies. For these reasons, SLM is analyzed as the method of AM for this case study.

When selecting a material for resistojet fabrication, the three of the most important features to consider are strength, electrical and thermal conductivity, and cost. The material must be cost-effective without sacrificing strength and conductivity. Another major factor to take into consideration is the material's ability to be formed into the thin-walled sections that a resistojet requires and, once formed, to withstand necessary temperatures and pressures. With respect to material, resistojets have been fabricated successfully of materials such as rhenium, Inconel 718, 316L stainless steel, and copper.

Resistojets are usually a combination of two components: a heating chamber and an exit nozzle. These two pieces serve different purposes and, therefore, must satisfy different criteria. A key quality of the heating chamber is that the material must be able to structurally withstand the internal pressure and temperatures as a thin-walled component. A cobalt–chrome alloy, Co-28Cr-6Mo, is recommended by Electro Optical Systems [33] (EOS) for thin-walled situations (i.e., the heating chamber) and it has the highest operating temperature of around 1150 °C [34]. Inconel 718 is viable material option for the exhaust nozzle. Titanium alloys are another option because they are capable of high strength, but do not perform well at high temperatures, such as those that the exhaust nozzle of the resistojet would need to sustain. Co-28Cr-6Mo and Inconel 718 are nearly similar in cost when sourcing from Stratasys [32]. For the conceptual nature of this project, both a single-piece resistojet and a two-piece resistojet are analyzed. The single piece is made entirely of the cobalt–chrome alloy, and the two-piece has a cobalt–chrome heating chamber and an Inconel 718 nozzle fixture. These two concepts are shown below in Figure 7, with the Inconel nozzle outlined in red.

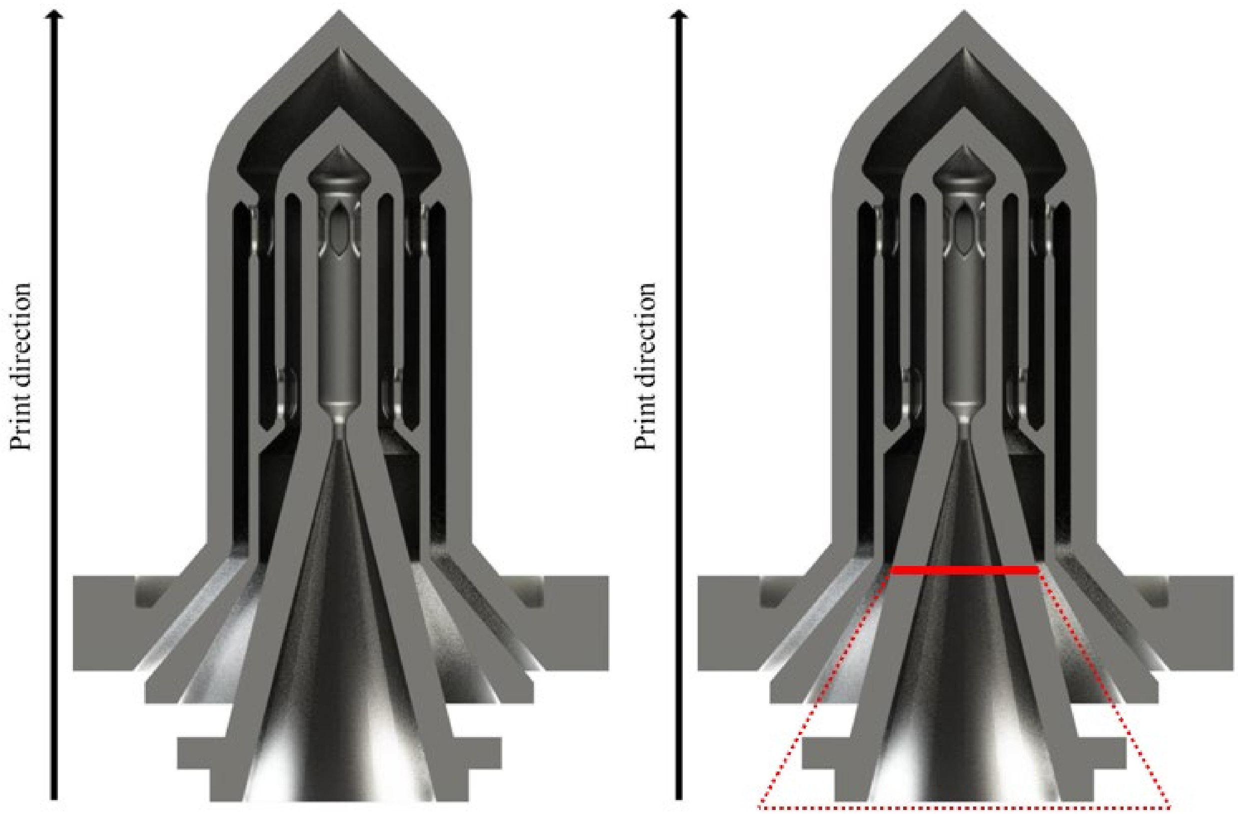

Figure 7: Single-piece prototype (left) versus two-piece resistojet design (right) [35]

For these two resistojet design concepts, Stratasys On-Demand Parts could serve as fabricator since they have the same price point for both materials under SLM conditions. The single component model should be designed with as little postproduction as possible. This approach would help to keep costs down and decrease time from design to completion. With no welding or joining process required, this resistojet could be fully fabricated during a single run of an SLM machine. Looking at other research, SLM production can be performed with up to

99.7% accuracy [34]. This level of accuracy is an exceptionally good indicator that the parts will be successful after a few design iterations.

The areas of largest concern occur inside of the heating chamber and its fuel flow paths. This would be the case for both fabrication methods, as cobalt–chrome material is to be used for this component. For the single-piece resistojet, the biggest concerns are the structural integrity of the heating chamber and the performance of the cobalt–chrome nozzle. While being harder to produce, Inconel 718 is more suited for the nozzle [34].

The challenges with the two-piece resistojet come in welding the joint between the cobalt–chrome heat chamber and the Inconel 718 nozzle. Inconel 718 is 17–21% chromium and contains traces of cobalt and molybdenum [36]. These three elements make up the Co-28Cr-6Mo alloy that will be used for the heating chamber. Inconel 718 can be welded using TIG welding, but requires very high temperatures. The issues come with the cobalt–chrome alloy as cobalt releases a toxic gas when welded called hexavalent gas [37]. This gas requires an oxygen tank to be worn by the welder. Aside from this issue, cobalt can be welded. TIG welding using argon gas can also be utilized when joining these two pieces. Other methods like remote laser beam welding could be used. The main problem with this joint is the structural integrity as well as the temperature needed to successful join the two materials together. If the joint can withstand the temperatures of the exhaust nozzle, this is a good option for these two materials to function at their best. Post processing would need to be done after the weld to make it cohesive and blended to work properly with both the heating chamber exit and nozzle entrance geometries. Whenever post processing is involved, the cost and complexity of the part rises. It can lead to potential processing errors and are a factor in deciding which method is best. However, the proposed solutions are possible, but require additional research.

Chapter 6

Conclusion and Future Work

Metal additive manufacturing technologies can be used in the production of vaporizers for aerospace applications. The possibilities of using this evolving technology are significant as its use can reduce costs and production time in fabricating these components. Resistojets are becoming more prevalent on space platforms, which drives the need to produce resistojets and other vaporizers cost-effectively. The use of SLM with the right materials such as Inconel 718 and Co-28Cr-6Mo may be a cost-effective method for their production.

Using these recommendations, future efforts would begin by designing a solid model for both styles of resistojet. Using CAD software such as SOLIDWORKS, a full-scale solid model can be drafted and converted to an STL file, which can be sent out to Stratasys and other companies that specialize in SLM printing. After fine-tuning and adjustments, final iterations can be reached for both solutions. For the two-piece solution, contacting a skilled metallurgist and welder would be required. Testing of the joint between Co-28Cr-6Mo and Inconel 718 would confirm the structural integrity of the weld joining these two materials.

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ACADEMIC VITA

Charlie Canby

Education

Bachelor of Science in Aerospace Engineering May 2021
Minor in Information Sciences and Technology
Pennsylvania State University || Schreyer Honors College

Work Experience

Textron Systems June 2020-August 2020
Quality Engineering Hunt Valley, Maryland

- Performed Critical Safety Item Reviews to identify possible concerns with planning and processes. Closed 190+ overdue reviews and contributed to retirement of 20+ out of service parts.
- Ballooned and labelled engineering drawings for First Article Inspection procedures. Recorded Purchase Orders and Discrete Jobs for 400+ parts in an Annotated BOM.
- Tested and documented Nonconforming Quality Metric tools to identify possible logic errors in data analysis. Identified Purchase Order Codes to be removed from high yield parts to increase space in CMM Inspection. Reduced inspection procedures for 50+ parts at receiving inspection.

General Electric Aviation May 2019-August 2019
Engineering Supply Chain Manufacturing Hooksett, New Hampshire

- Performed data analysis to determine root causes and corrective actions for various parts in the shop. Created spreadsheets for future use to organize CMM data easier.
- Reintroduced airfoil leading edge laser software to help technicians accurately rework lead edges on blisk airfoils. Proposed savings across one engine line were $33,300 per year.
- Reformed a part marking process in shop. Created and 3D printed fixtures, revised work instructions, and assisted the creation of new programs. Proposed savings were $13,000 per year.

General Electric Aviation May 2018-August 2018
Engineering Component Repair Service McAllen, Texas

- Closed 50+ Quality Concern Reports from Process Line Engineers and Shop Floor Technicians.
- Participated in action workouts to reduce hours of rework necessary while performing the braze preparation tasks in the shop.
- Prepared a business presentation for the substantiation of a grinder and polisher in the Metallurgy Lab. Proposed savings were $34,000 per year.

Involvement

Collegiate Wind Competition Club September 2017-May 2018
Team Member Pennsylvania State University

- Ran power and wind speed projections for airfoil geometries using Excel code and an airfoil generating software for the aerodynamics team.
- Created carbon fiber renditions of different blade geometries and tested them in a wind tunnel.

Skills

- Microsoft Suite, SolidWorks, Matlab, InspectionXpert, Siemens NX