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LARGE-SCALE IDENTIFICATION OF PARTS SUITABLE FOR ADDITIVE MANUFACTURING: AN INDUSTRY PERSPECTIVE

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Abstract

Additive manufacturing (AM) has many potential benefits to the aerospace industry, especially when low production quantities are required. These benefits range from lightweight and complex geometries to reduced setup costs and lead time. One of the largest challenges to introducing AM into an existing aerospace vehicle is identifying which parts are candidates to be printed. This paper identifies a number of criteria that can be used to quickly filter parts into three categories: Printable As-Is, Easily Redesigned for Printing, and Not Printable Parts. The criteria are also broken into three tiers based on their level of impact on eliminating parts from the selection process. As a demonstration of these criteria, a case study is performed on a suborbital rocket, consisting of over a thousand unique parts. A flow chart is provided to guide the implementation of the filtering criteria, as well as methods to adapt the criteria to different industries.

Introduction

Additive Manufacturing (AM) is a field that has been growing due to the benefits that this new production method offers in many industries, including the aerospace industry. Additive manufacturing has the ability to produce complex geometries and lightweight parts without the cost of extra machine time [1]. It can also be used to combine parts of an assembly to reduce the total part count and assembly time [2]. Industries with low part quantities, such as the aerospace industry, benefit from reduced prices with AM [3]. This benefit is gained by the elimination of specialized fixtures and tooling that are required for traditional machining processes. The challenge to companies is determining how to incorporate AM into their existing product lines and identify which parts are candidates to be printed.

Parts that have been designed for traditional manufacturing processes cannot always be successfully printed without modifications to the design [4]. This is because, despite all of the benefits of additive manufacturing, there are limitations that can prevent a part from being printable. Some of these limitations include wall thickness, part size, material properties and printability, surface roughness, and support design and removal [5]. For a new part, these limitations are addressed during the detailed design phase [2]. However, existing parts do not have the benefit of being modified without significant cost to the company [6]. Changing the design of an existing product can be costly, especially in the aerospace industry. Costs associated with making a design change include the labor and time associated with reviewing and revising the drawing, notification of the change to suppliers, distributors, and end users, and recertification or requalification of the part. For these reasons it is desirable to avoid making changes by identifying parts that can apply additive manufacturing as designed. Therefore, there is a need to be able to rapidly and efficiently identify industry parts that can be produced using additive manufacturing without requiring modifications to the design. However, the process of identifying candidates for additive manufacturing can be difficult and time consuming.

Two main approaches to identifying viable candidates for AM have been identified in literature, a bottom-up or top-down approach [3]. A bottom-up approach consists of reviewing each design and identifying if the part is a candidate for printing based on the features of the part and benefits from applying AM. One method proposed by Lindemann et al. consists of holding a series of workshops through which designers and experts identify and analyze designs for their compatibility with printing [4]. The first of these three workshops is the Information Phase and is intended to introduce the additive manufacturing technology and part screening process. In this workshop, participants are taught the basics of the additive manufacturing process and design aspects that need to be considered during the design process. Participants are then able to submit candidate parts by entering them into a trade-off methodology matrix (TOM). The suggested parts are then assessed by AM experts and part owners during the second workshop. During this Assessment Phase the suggestions are ranked based on the following design aspects: size limitations, part classification, suppression of assemblies, post-processing needs, existing material use in the industry, geometry conditions, material properties, material consumption, and processing time. The three highest ranked parts from this assessment are taken to the Decision Phase. This final workshop reviews the parts for material compatibility, material consumption, processing time, and economic aspects. This approach provides a well-structured method of filtering candidate parts and identifying the main functions of a part to be accounted for in the redesign of the part for AM. However, this is a long process that involves many people and still relies on modifications to the part.

A second bottom-up method is provided by Simkin and Wang by approaching the problem from the supply chain perspective [7]. They identified seven scenarios in which additive manufacturing might be more cost-effective to produce a part. These scenarios occur if the original part is expensive to manufacture, has long lead times, has a high inventory cost associated with it, comes from a sole-source supplier, is needed in a remote location, has high import or export costs, or if the part would benefit from improved functionality of an additive part. Based on the applicability of these scenarios it can be determined if the part would benefit from additive manufacturing from a cost perspective. The parts that are identified by this process need further analysis to assess their printability and may require redesign.

The top-down approach to identifying candidate parts for additive manufacturing shifts the focus from the printability of the part to the applicability of the criteria used to filter through the parts. An example of this approach is provided by Knofius et al. [3]. In this work, a database containing hundreds of thousands of spare parts for service logistics were filtered to identify more than 1,000 business cases in which additive manufacturing offered a benefit to the company. This method focuses on the benefits to the supply chain process that additive manufacturing would bring, such as shorter lead times and lower stock quantities. This process consists of identifying part supply attributes that would be improved by implementing AM, assigning a weighted value to the attribute, and calculating scores for the parts based on the weighted attributes. The attributes were limited to information available in company databases and consisted of the demand rate, resupply lead time, agreed response time, remaining usage period, manufacturing/order costs, safety stock costs, number of supply options, and supply risk. The company’s goals were used to determine the weight of each attribute in the scoring process. The more aligned the attribute was with the company goals, the higher its weight. After the parts have been scored, the high scoring parts can then be assessed for printability on the design aspect level. The benefit to this approach is that it takes into account the lifecycle costs of the spare part and identifies opportunities that might have otherwise been overlooked.

The existing methods of identifying candidates for additive manufacturing each fall short in one aspect or another. Both of the bottom-up approaches have their benefits, but do not address the need to identify parts that can be printed without requiring modifications to the design. The bottom-up approaches presented are time consuming, because they focus on individual parts or require multiple meetings to identify parts. The top-down approach quickly filters through parts but does not focus on the features of the parts. It is only focused on aspects of the supply chain process that would benefit from AM and not the design aspects that actually determine if a part can be successfully printed. This approach requires a secondary analysis to determine printability. All of these approaches will help identify parts that can be produced through additive manufacturing, but will require different amounts of information, time, and effort.

Methodology

In an effort to combine the benefits of the bottom-up and top-down approaches, this work will follow a top-down filtering process that is focused on the design aspects of the candidate parts. The design aspects will be used as criteria to eliminate parts as candidates for printing. The top-down part of the approach comes through determining which design aspects are the most effective at eliminating parts. In this way, a large number of parts can be filtered in a short amount of time. A conceptual flow chart of the entire process is provided in Figure 1.

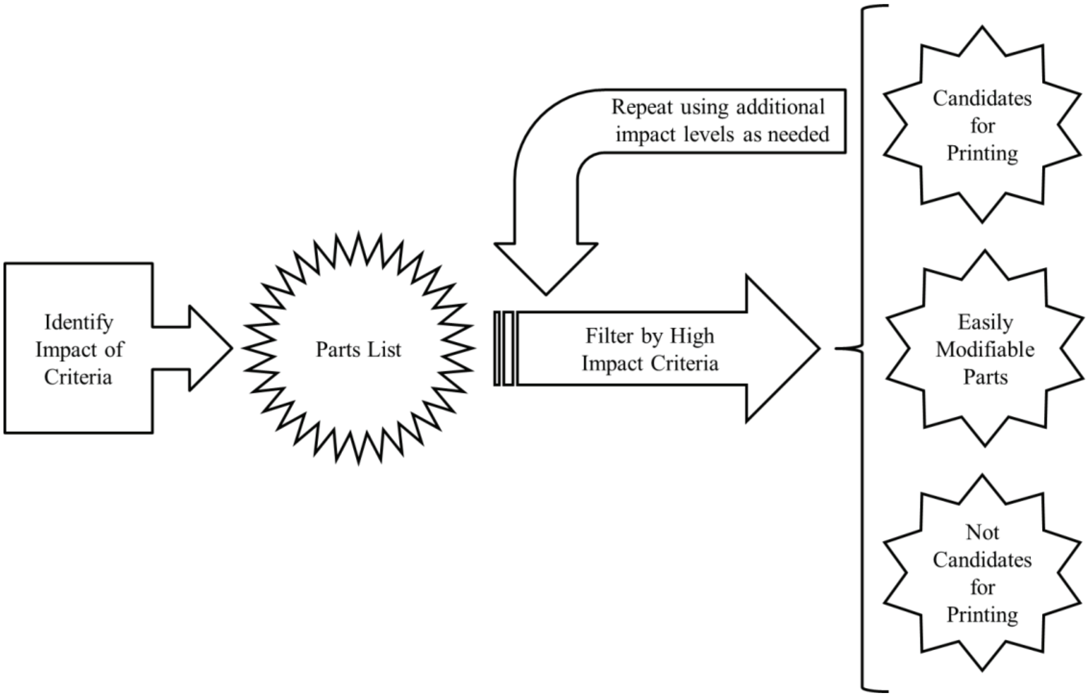

Figure 1: Candidate Part Identification Process Flow Chart

The filtering criteria are developed based on their effectiveness at eliminating parts as candidates for printing. The effectiveness of each design aspect can change depending on the application and industry. For example, the part quantity criterion would have a higher impact for industries with high volumes than it would for the low volumes seen in the aerospace industry. The different design aspects are separated into three levels based on their impact on eliminating candidate parts. The parts list is then filtered using the criteria from the high impact level. If additional filtering is required to reduce the number of candidate parts then the filtering process can be repeated with the remaining filtering levels. In this way, a parts list can be quickly filtered, with the parts that remain being candidates for printing without requiring design modifications. During the filtering process, it is also possible to identify parts that can be easily modified to be printable. These simple modifications could consist of changes to the material selection, feature size, or wall thicknesses. This top-down filtering approach can be applied to various industries and applications by identifying the appropriate impact of the criteria prior to applying the filter. This enables easy adaptation for multiple applications including spare parts, long lead time items, and low volume parts [3].

Criteria Development

To create the filtering criteria, different attributes from the design for additive manufacturing (DfAM) literature were reviewed. These attributes were assessed based on their impact on eliminating parts from the pool of candidates and ranked by their effectiveness. The DfAM aspects considered are similar to those discussed by several researchers, such as the design heuristics presented by Blösch-Paidosh [8], the design worksheet developed by Booth [9], and the design guidance from Pradel [10]. These design aspects are typically used as guidance in creating new designs, but will be used as criteria for eliminating parts in this application. These design aspects contribute to the probability of a part printing successfully. Therefore, they can also be used to determine the likelihood of a part failing during the printing process. The design aspects will be assessed and their impact determined based on the number of parts that can be eliminated as candidates. For example, high impact criteria will be those that eliminate a large number of parts. Note that the level of impact of each criteria may change based on the application and industry in which it is being applied. For this study, the impact levels are determined based on an aerospace industry application, which has low part quantities, high load levels, and high part costs. The design criteria are broken up by their impact levels and are provided in Table 1 through Table 3, each of which will be discussed in turn. The quantitative impact of each criterion within the high impact group will be shown later, as it applies to a chosen case study.

High Impact Criteria

To be considered a high impact criterion, the design aspect needs to be easy to apply based on the available information for each part and eliminate a large number of parts from the candidate pool. The design aspects that meet these requirements for this aerospace application consist of: hardware and commercial off-the-shelf (COTS) parts, assemblies, material, load environment, part size, and cost. Hardware, such as nuts and bolts, and commercial off-the-shelf (COTS) parts have a high impact on eliminating candidates for printing. Hardware is typically mass-produced by companies with special tooling for the process, making the parts inexpensive and stronger than printed versions. COTS parts consist of a range of part types that provide a better value from being purchased than designed and manufactured in house. These parts are not considered good candidates for printing. Identifying assemblies is another effective filter for eliminating parts from printing. Assemblies cannot be printed without making changes to the design and thus are not considered printable in this work. Typical assemblies include electronics, cables, and inseparable assemblies (parts with hardware permanently attached). A third high impact criterion is the material of the part. This criterion eliminates parts made from non-printable materials, such as composites, ordinance items and thermal protection systems (TPS). To be a direct replacement, the same or adequately similar material (based on its properties) is required. A part could be considered easily modifiable if the original material could be replaced for a printable one. An example of this would be changing the material of a spacer from metal to a printed polymer.

Another high impact criterion is the load environment of the part. The required strength of the part limits the materials and processes that can be used, which can make the part unprintable. For this application, the major structural components are eliminated by this criterion due to the high loads and critical nature of the parts. Industries are moving towards a higher criticality of AM parts [11]. However, for the purposes of this work, the desire is to find parts that can quickly apply AM without the need for a significant amount of additional analysis and qualification. The part size criterion eliminates parts that are larger than a given print volume. The feature size in a part is also considered with this criterion. Parts that have features that are problematic for printing, such as small details, thin walls, and large flat areas, are grounds for elimination. Parts can also be eliminated that have the shape of stock materials, such as a flat plate or round rod. Note that the impact of this criterion can change based on the type of product or the capacity of available printers. It is also an easy criterion to assess due to the availability of information on the part dimensions. Another criterion in the high impact group is the cost of the part. The cost of the printed part cannot be higher than the current manufacturing process in order to be considered for printing. Although the cost is anticipated to be effective at eliminating parts as candidates for AM, it should be the last criterion to be reviewed. This is due to the extra effort required to collect information on the cost of the parts. By waiting until the end, fewer parts need to be reviewed.

Table 1: High Impact Design Criteria

Criteria	Rejection Level
Hardware / COTS	Not candidates for printing
Assemblies	Not candidates for printing
Material	Material must be printable and have equivalent properties
Load Environment	High load levels and critically loaded parts
Part Size	Parts with a dimension larger than 4’ (1.2 m), walls that are 0.125” (3.2 mm) or thinner, or resemble common stock shapes
Cost	Printed cost must be lower than current cost

Medium Impact Criteria

The design aspects in medium impact level may not be as effective at eliminating parts as candidates for printing and can be more difficult to apply. This is due to the number of parts the criteria eliminate and the amount of time and effort to obtain the information that is required to make the assessment from multiple sources. These criteria, listed in Table 2, would be applied after the high impact criteria, if needed, and consist of: manufacturing complexity, part application, testing or qualification requirements, lead time, quantity, post processing, and conductivity. Additive manufacturing excels in creating geometry that is difficult to produce by traditional means. Conversely, a low level of manufacturing complexity (such as simple plates, sheet metal parts, and parts that can be machined without repositioning the part) can eliminate a part as a candidate. The part application criterion can be broken into three categories; Critical Components, Nonstructural or Secondary parts, and Non-production parts. This criterion is closely coupled with the testing and qualification criterion. Each application has its own grounds for elimination. Critical components have the most restrictive requirements due to the risk of a catastrophic failure [11]. Making changes to these types of parts will require additional analysis, testing and requalification of the part. For the aerospace industry, these types of parts would all be eliminated as candidates for printing. The second application is Nonstructural or Secondary parts. These parts are less restrictive and typically only require a test coupon to be printed and tested to verify the material properties. This makes them possible candidates for AM, if they haven't already been eliminated. The third part application is non-production parts that are typically used as tooling or manufacturing aides. These parts are typically good candidates for printing as they do not have the same level of requirements as the other two applications.

The next medium impact criterion is the part lead time. This is considered a medium impact because the information is not readily available and requires additional time and effort to obtain. Lead times can also vary based on demand at the supplier, making it less reliable to use. The part quantity criterion would eliminate parts that are produced in large volumes due to the benefits of scale from using other processes, such as injection molding. Since the aerospace industry typically deals with low-volume parts, this criterion is not as effective as other criteria at eliminating parts. The amount of post processing required on a part can eliminate it as a candidate for printing. Situations that would require post processing are mating interfaces, support removal, and parts that require a higher level of surface finishing. This adds to the time and cost of the printed part, which may eliminate the part as a candidate for printing.

Table 2: Medium Impact Design Criteria

Criteria	**Rejection Level**
Complexity to Manufacture	Parts that can be machined without repositioning the part
Part Application	Critical components
Test/Qualification Requirements	Parts that require additional testing or qualification
Lead Time	Parts with less than 12 week lead times
Part Quantity	High volume (>1000)
Post Processing	Five post processing steps

Low Impact Criteria

The third impact level contains the design aspects that have a low impact on eliminating parts as candidates for printing, see Table 3. Assuming that the high impact and medium impact criteria have already been applied, this last tier may eliminate little-to-no parts or may be more useful in identifying parts to modify. Low impact criteria consist of: fatigue, surface finish, weight savings, potential for part consolidation, potential for customization, and conveying information. Fatigue was considered a low impact based on the particular aerospace application considered for this work. However, in other industries and aerospace applications fatigue may be a higher impact item. Printed metal AM parts often contain voids within the part caused by the printing process which can significantly reduce the fatigue life of the part [12]. The surface finish was also considered a low impact design aspect based on the chosen application. The surface finish is usually not a critical design aspect, unless the part contains a mating interface or fatigue is a concern. For printed parts, the surface finish can often be addressed through post processing. The remaining low impact design aspects do not eliminate any candidate parts, but can identify parts that can be modified. Weight savings is primarily achieved by changing the density of the infill of the part or optimizing the topology of the design. Both of these approaches would be a deviation from the existing part and would require changes to the original design of the part. The potential for part consolidation and the potential for customization both rely on changing the part, which could identify parts for modification rather than elimination.

Table 3: Low Impact Design Criteria

Criteria	**Rejection Level**
Fatigue	The part requires fatigue testing
Surface Finish	Six features require post processing
Weight Savings	Identifies potential modifications
Potential Part Consolidation	Identifies potential modifications
Potential Customization	Identifies potential modifications

Case Study: Suborbital Rocket Booster

The intent of developing these different criteria tiers for identifying parts suitable for additive manufacturing was to be able to apply them to an existing aerospace product. A case study was used to help develop the filtering criteria and to validate the process. This process, as shown earlier in Figure 1, consists of identifying the impact of the filtering criteria specific to the industry and application, obtaining the parts list, and filtering the parts list by impact level to eliminate parts unsuitable for AM. If filtering by the high impact level criteria reduces the list of candidate parts to a manageable size, further filtering may not be required. However, the filtering process can be repeated on the results using a lower impact level to further reduce the number of candidate parts. In this case study, filtering by the high impact design aspects was sufficient to reduce the number of candidate parts. The product used to define the impact levels and verify the application of the criteria is an existing design of a suborbital rocket. This rocket is one of multiple products of a globally dispersed defense company and is based on many existing flight proven designs. There is a strong desire to maintain the reliability of the heritage designs while also introducing the benefits of the additive manufacturing process. For this case study, only the booster section of this rocket was considered due to the sensitive nature of information about the payload. The booster section consists of the first two stages of the rocket which contain over 3,000 total parts and more than 1000 unique part numbers. A conceptual image of such a rocket is shown in Figure 2.

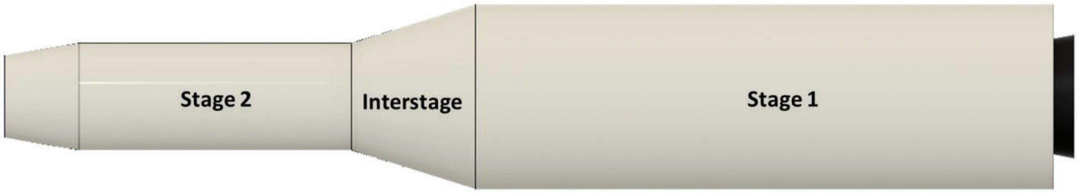

Figure 2: Suborbital Rocket Booster Section Example

The first step of the filtering process, defining the impact levels of the criteria, was performed previously as part of the criteria development section. The next in the process is obtaining a complete parts list, including all the subassembly levels. This was generated for the entire booster section of the rocket by exporting the assembly structure from the CAD model into a spreadsheet.

Besides the part number and name, the key information obtained from this parts list is the weight and material of the parts. Additional columns were added to compare the current and estimated costs and to track the categorization of the parts. Cost information was not obtained for all parts as it was the last criterion applied. The AM cost of the parts was estimated at $200 per pound based on previously published rules-of-thumb [13]. As parts were eliminated as candidates for printing, the criterion that eliminated them was tracked. An example section of this spreadsheet with the results of the filtering process is provided in Table 4.

Table 4: Sample Filtered Parts List

Part Number	Name	Qty	Weight (lb)	Current Cost	AM Cost*	Material	Candidate	Elimination Criteria
123-2519-001	Detonator Assembly	1	0.056		$11.20	N/A	No	Assembly
T063-270-375R	Spring, Torsion, RH Wound	1	0.02		$4.00	Aluminum 6061	No	COTS
123-7818-001	Plate, Mounting, AFT Dome	1	1.762	$170.00	$352.46	Aluminum 6061	No	Size - flat
123-1401-96	Ring, AFT Skirt, External TPS	1	1.644		$328.72	Cork ABL-5	No	Material
123-1301-99	V-Band, Stage 1, AFT Skirt	2	7.017		$1,403.38	Aluminum 7075	No	Load
123-7804-97	Block	1	0.906	$894.00	$181.10	Aluminum 6061	Yes	None
123-1726-001	Bracket	1	0.256	$377.00	$51.18	Aluminum 6061	Yes	None
123-1710-001	Boot, DV Motor - 70 Degree	2	14.252		$2,850.38	Steel 17-7PH	Yes	None
123-1851-001	Bracket, TT, Connector	1	0.179	$378.00	$35.82	Aluminum 5052	Modifiable	Size - sheet metal
123-4080-001	Spacer, SE13G Battery	2	0.152	$110.00	$30.50	G10	Modifiable	Material
123-1171-001	Housing, Li-Ion Battery	1	0.869	$295.00	$173.80	Aluminum 6061	Modifiable	Size - thin wall
123-5300-001	Tie Base, Swivel	32	0.0082		$1.64	ABSPlus-P430	Printed	N/A
123-1880-002	Bracket, Connector, SS21	1	0.0678		$13.56	ULTEM 9085	Printed	N/A
123-1880-001	Plate, Connector, SS25	1	0.0639		$12.78	ULTEM 9085	Printed	N/A

*The cost AM parts was estimated by assuming a cost of $200 per pound for AlSi10Mg or stainless steel 316L. This estimate was based on previously published rules-of-thumb [13].

The first step in applying the high impact criteria was to focus on the criteria that would identify parts that were not printable. The initial filtering consisted of eliminating all hardware, COTS, and assemblies. In this application, only military specification and industry standard hardware were used. The part number column was filtered using the typical prefixes associated with these types of parts. Next, the part number column was filtered for non-company part numbers to identify the COTS parts that could be eliminated. Then, the list was filtered for assemblies and those items were marked for elimination. In this case, assemblies consisted of modules, cables, circuit card assemblies (CCAs), and electronic components. For this case study, the main structural components of the rocket were not considered printable due to the high load environment and could be filtered from the list. The material criterion was applied by utilizing the material column of the parts list. This made it easy to identify parts that were already printed or that were made of materials that could not be printed. The parts that were already printed were identified by their unique materials, such as Ultem 9085 or ABSplus-P430. The materials that could not be printed consisted of composites, silicones, and cork.

The next step in the process was to go through the remaining parts line by line to categorize the parts into one of four categories, printable, easily modifiable, not printable, or more information needed. Each part was reviewed against the criteria to determine if it was a candidate for printing. As nonprintable parts were identified, the driving criterion for their elimination was noted. If the parts list did not contain enough information to assess the printability of the part, they were marked as requiring additional information. This additional information was then obtained from the drawing and CAD model of the part or through the supply chain database. The additional information needed for the assessment consisted of part dimensions, including feature sizes, or the cost of the part. As information was gathered on these items, the final assessment of their printability could be made. During this process, similar types of parts were recognized that could help speed up the process by applying the same printability status to them. A few examples of some of these parts types are doors, skins, tubing and bulkheads. Parts were determined to be easily modifiable if they contained less than three features that required modification. This was based on the amount of effort that would be required to redesign the part. Features that could be modified consisted of thin walls, large flat areas, and the material of the part.

This case study reviewed 1,073 unique parts to identify candidates for additive manufacturing. After applying the filtering criteria, 89 parts were identified that could potentially be produced using additive manufacturing as-designed. This represents 8.3 percent of the total parts reviewed. A summary of the results is provided in Table 5. Hardware was removed from the total part count as it was known from the start of the process that it would not be considered for printing. In addition to the parts identified as candidates for additive manufacturing, 14 parts were identified as being easily redesigned to become printable. The modifications required to make these parts printable are eliminating thin walled sections, changing features on sheet metal parts to be more printable, and changing the material. Sheet metal parts are designed with features that are specific to that process (tabs, bend radius, etc.), see Figure 3. These features can be difficult to print, but can be modified to print more successfully. There are a few cases where the easy redesign was to change the material. One example was a thermal isolating plate made of G10, a fiberglass laminate material. This part could be printed with Ultem 9085, which has similar thermal properties.

Table 5: Case Study Results Summary

Part Category	Total	Percentage
Already Printed	30	2.8%
Printable As-Is	89	8.3%
Easily Redesigned	14	1.3%
Not Printable Parts	940	87.6%
Total Parts Reviewed*	**1073**	100.0%

*Hardware not included in total count

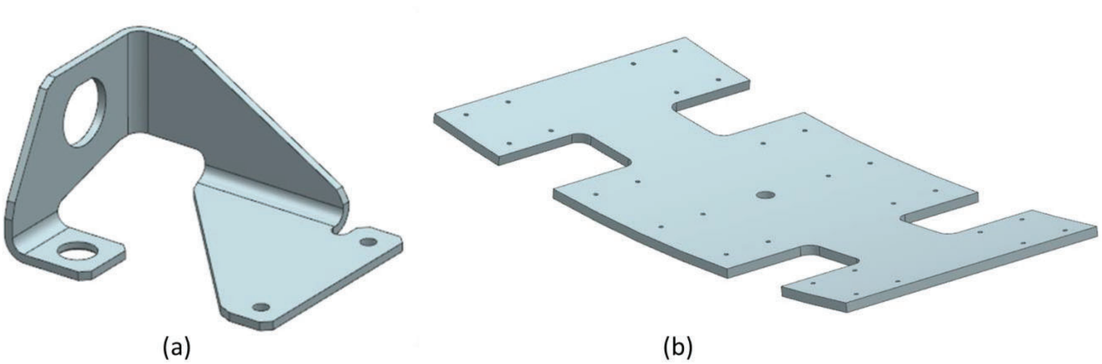

Figure 3: Sample Parts: (a) Sheet Metal, (b) Common Stock

The majority of the parts in the rocket being studied were determined not to be candidates for additive manufacturing. These parts were eliminated based on five of the high impact criteria presented earlier, as shown in Figure 4. The majority of the parts were eliminated as commercial off-the-shelf (COTS) components, representing nearly twice as many parts as any other category. The second largest group of parts was assemblies. None of the parts were eliminated by the cost criterion. The main reason for this was that the cost information was reviewed last. Information on the cost of the part was not on the initial parts list and thus required extra effort to obtain. To reduce the effort of obtaining cost information, the parts were reviewed against all the other criteria first. This meant that many parts were eliminated before the cost information was obtained.

Part Elimination Criteria	Total	Percentage
COTS	384	40.9%
Assembly	209	22.2%
Material	127	13.5%
Load Environment	112	11.9%
Part Size	108	11.5%
Total	**940**	**100%**

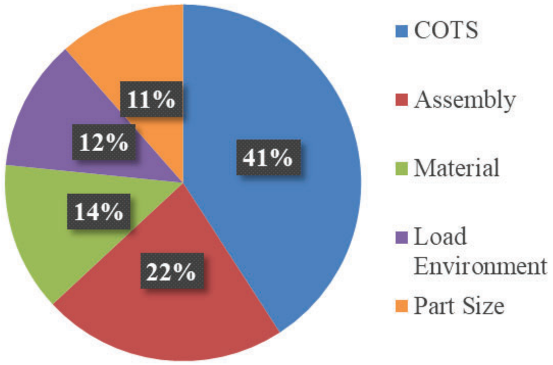

Figure 4: Parts Eliminated by Criteria

Although the part size criterion eliminated the least amount of parts, it was the most involved criterion. There are several different aspects to the part size that could eliminate a part as a candidate for printing. Four subcategories were identified while applying this criterion in the filtering process. These categories are thin wall, small feature, common stock, and sheet metal. Figure 5 shows the part size subcategories and their distribution within the category. Some parts were eliminated because they contained thin walls or small features that would be difficult to print successfully. Other items were eliminated because they contained large flat regions that would be prone to warping or could more easily be made from common stock material. These parts were often simple rectangular plates with a series of holes drilled in them. This common stock subcategory accounted for 52% of the parts eliminated from printing based on the part size. The second highest subcategory was sheet metal parts. These parts were designed specifically for that manufacturing process. These parts do not transfer well into additive manufacturing as they are made from thin stock, usually 0.100 - 0.125 inches (2.54 – 3.175 mm), and are relatively inexpensive. Another observation about the part size criterion was that none of the parts were eliminated due to parts being too large. This was initially thought to be the main reason for elimination based on part size. For this analysis, it was assumed that parts could be printed on any existing machine. The EBAM 300 Series printer by Sciaky has a build volume of 19’ x 4’ x 4’ x 8’ (5.8 x 1.2 x 1.2 x 2.4 m) or round parts up to 96” (2.4 m) in diameter [14]. This printer is large enough to print any part of this rocket, even the structural components.

Part Size Subcategories	**Total**	**Percentage**
Thin Walls	16	14.8%
Small Features	6	5.6%
Common Stock	56	51.9%
Sheet Metal	30	27.8%
Total	**108**	**100%**

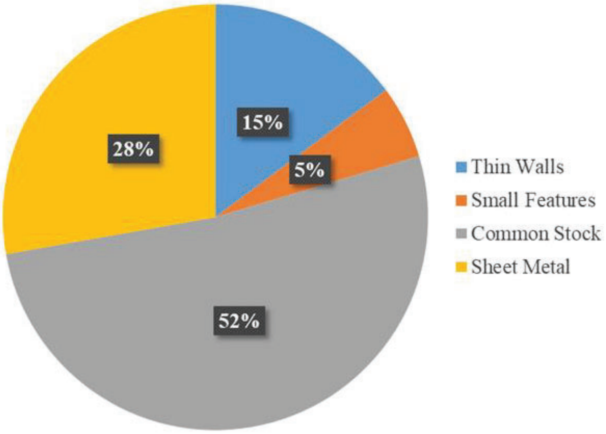

Figure 5: Part Size Subcategories Marked for Elimination

Conclusions

The criteria presented in this work are an effective way of identifying existing parts that are candidates to be produced through additive manufacturing. Employing this method of identifying candidates for printing can be beneficial to those industries wanting to incorporate additive manufacturing into their existing products. The case study of a suborbital rocket demonstrated that the application of these criteria can quickly identify a significant number of parts that are candidates for additive manufacturing. More than one thousand parts were reviewed using these criteria. Of these parts, 89 were candidates for printing with another 14 that could be easily redesigned for AM. The two major categories that eliminated the parts as candidates were COTS and assemblies. This process can also be extended to other products and industries. To apply this process in a different application, the criteria identified in Table 1 can be reviewed to determine their impact for the given design. Because each industry and application is unique, additional criteria can be added or removed. Industry or product specific requirements can also be added, such as the assumption that structural components would not be printed as shown in the case study. The parts list for the product can then be reviewed against the criteria to eliminate parts and identify those that are candidates for additive manufacturing.

This work has focused on a method to quickly identify parts that are candidates for additive manufacturing. The criteria were tailored towards eliminating parts. Improvements could be made to the criteria by identifying specific thresholds for each criterion at the start of the process, such as the allowable part size dimensions and minimum wall thickness or feature size. Defining these thresholds at the start will make the process faster and less subjective. The medium and low impact levels could also be applied to determine their actual impact on an industry application. The process and results could be further enhanced by obtaining more detailed information about the parts, such as the load environment, safety factors, current cost, and lead time. Even though this would add time to the process, it may help support the results. A better method of estimating AM part costs would also improve the results of this process. More research into adapting existing designs for additive manufacturing would be beneficial and could help identify additional parts for modification. These additions could improve the effectiveness of this work.

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