AIAA 2022-2023 Undergraduate Hybrid-Electric Regional Turboprop Aircraft

Analysis of Aluminum Recycling through the Social Construction of Technology

A Thesis Prospectus Submitted to the

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Bachelor of Science in Aerospace Engineering and Materials Science and Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Since the first flight of the Wright Flyer, the aviation industry has heavily influenced the modern world. Many would likely see this impact through the large-scale globalization of the world. A trip from Boston, Massachusetts to Tokyo, Japan takes only around 14 hours when, before commercial aviation, the trip would take months. However, there are many other impacts of this industry on the world around us, including planes that influenced the outcomes of wars in the past and the heavy use of aviation emitting significant amounts of greenhouse gasses into the air. Current research efforts focus on addressing the emissions of the aviation sector through utilizing developing electrical technologies such as batteries, motors, and generators.

My technical topic focuses on conceptualizing a way to reduce combustion and emissions for regional flights. This contains many potential benefits: for example, reduced emissions come with reduced fuel burn, which results in less spending on fuel. Often, more efficient aircraft are both cheaper to run and cause less damage to the environment. Our goal is to achieve such a higher efficiency by creating the conceptual design of a hybrid electric regional turboprop. A turboprop represents a specific propulsion system within the aircraft that utilizes turbine generators and propellors to create a highly efficient, air-breathing engine. Hybrid electric means that this propulsion system is coupled with some sort of electric power to increase efficiency, typically through reducing the amount of fuel burned. The end result of the technical project is a deep technical report on a conceptual design and evidence that it will adequately fit the needs in the regional aviation sector.

One of the biggest choke points for the development of aviation technologies is the materials available to use. This can range from the structural materials sustaining the loads of lift and drag, to functional materials providing sensing data to the pilots. On the structural side of materials, aluminum became the dominant material. Aluminum's high strength to weight ratio, coupled with its resistance to oxidation (rusting), and its relative abundance in the Earth's crust made aluminum a very strong candidate for aviation (Ashby, 2007). The development and application of aluminum has been heavily influenced by social factors across history. The extent of extraction and recycling, the development of various aluminum alloys, and the application of aluminum are all socially constructed. The STS portion of this prospectus will propose applying the Social Construction of Technology (SCOT) methodology to the development of aluminum to answer the following questions:

1. How did the needs of the aviation industry and the globalization of the world affect the development of aluminum and its alloys?
2. How did the push towards recycling influence the application and development of aluminum and its alloys?

The former question represents the connection between my STS project and my technical project in that they focus on commercial aviation. Both questions also tie in well with my second major: Materials Science and Engineering.

This Prospectus will first detail my technical project by identifying the task and overviewing what has been done and what will be done. Then, this prospectus will explain my STS project, examine the research question, identify relevant social groups for both STS questions, and show a timeline for my thesis.

Technical Topic: AIAA Hybrid Electric Regional Turboprop

My technical topic revolves around one of the 2022-2023 University of Virginia Mechanical and Aerospace Engineering Department's senior design project: Aircraft Design. Specifically, it revolves around the American Institute of Aeronautics and Astronautics (AIAA)

"Hybrid-electric Regional Turboprop" Request for Proposals (RFP). The class was split into two teams of nine members who each have to go through preliminary design processes to create a unique aircraft utilizing some sort of hybrid-electric propulsion under restrictions listed in the RFP. The main purpose of the RFP is to encourage more sustainable aviation and increase operating efficiency through the use of hybrid electric technology. The aircraft must be designed under a strict set of performance requirements which focuses the technology on regional flights. Some examples of these include the passenger requirement of approximately 50 people, the maximum range requirements of 1000 nautical miles (~1150 miles) and the optimal range of 500 nautical miles (~575 miles). The driving points of this design is a 20% increase in efficiency and a reduction in emissions while developing an aircraft with possible entry into service of 2035. The complete conceptual design will be submitted May 2023 for the AIAA design competition (*Hybrid-Electric Regional Turboprop Hybrid-Electric Regional Turboprop RFP*, 2022).

The first task of my group was to analyze the RFP and develop and understanding for the requirements of the task. Through this, we developed a System Requirements Review (SRR) presentation to highlight key comparator aircraft and also possible design challenges. Then, the group was split into subgroups to conduct research on state-of-the-art technologies related to the aircraft, from propulsion to regulations. My group was tasked with researching propulsion systems and thermal management systems that could be applied to hybrid electric aircraft.

Moving forward, we began the design phase as our group conceived 9 possible designs and, through collective intuition, we down-selected to 3 designs. From there, we coded various iterative methods obtain an initial estimate for the Takeoff Gross Weight (TOGW), which is the weight of the aircraft just before takeoff including the fuel needed for the mission. Then, we developed a plot known as the matching plot for the aircraft. This plot is graphical way to represent two variables that we would like to optimize along with the constraints placed on them in various scenarios. Figure 1 shows an example of a matching plot, designed specifically for the ATR 72 propeller airplane. The two variables to optimize are on the axis as power to mass ratio (PM) and wing loading (WL), while constrains are displayed as lines with a hash on the prohibited side. Power to mass ratio represents the ratio between the total power output of the aircraft to the total mass of the aircraft and is a useful parameter as it often dictates whether the engines used are too small or too large for takeoff and cruise requirements. Similarly, wing loading is the ratio of the aircraft weight to the area of the wings, which is a good indicator of the forces on the wing and therefore efficiency or maneuverability of the aircraft. Through this, an optimized aircraft size can be determined (Gogu et al., 2011).

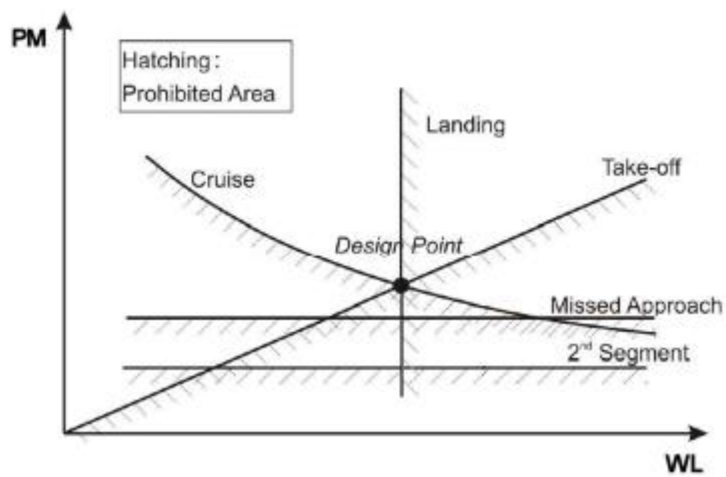

Figure 1. Matching chart for ATR 72 (Gogu et al., 2011).

From these, we will move into the Spring semester with a good idea of what the aircraft should look like. Beginning in January, we will use the information gathered in the fall semester to select one of the three designs. Then we will utilize software tools like Flight Optimization System (FLOPS), Open Vehicle Sketch Pad (OpenVSP) and GasTurb, to model the aircraft and demonstrate that it can meet all the requirements stated within the RFP and begin writing the results as a report to submit to AIAA.

STS Project: Aluminum and the Social Construction of Alloys

Aluminum is one of the most common metals, behind only iron and iron-base alloys (Schlesinger, 2013). The development of aluminum alloys can be thought of as a form of technology as it fits many definitions of what a technology is. This means that by SCOT, the development of aluminum is fundamentally influenced by social behavior. Because of the extent to which aluminum is used in modern day, along with the wide variety of aluminum alloys, the social construction of everything about aluminum would result in a scope that is too wide for this thesis. Thus, the focus of my thesis will revolve around two main aspects of aluminum stated in the introduction to this prospectus: how the recycling industry and the aviation industry have socially constructed the development of aluminum.

Aviation is a main driver for aluminum development, evidenced by how the importance of aircraft in warfare came about around the same time in which industrial processes for refining aluminum did (Chemello et al., 2019). In modern day aircraft, aluminum typically composes a significant portion of the airframe. This is not only due to the desirable properties of aluminum, but also the abundance. However, this was not always the case, as aluminum was once considered a rare and precious metal, even as the Wright brothers flew their first plane which was structurally made of mostly wood. However, aluminum was used for the engine block out of strength and weight requirements (Chemello et al., 2019). Since then, aluminum has taken the foreground in all aerospace structures. Only recently has more complex composites, like carbon fiber reinforced polymers, begun to challenge aluminum in this role.

Key social groups that affected the development of aluminum for aviation include aircraft designers, who are limited by the materials given to them, and must design within tight parameter requirements. Furthermore, the common people who frequently utilize commercial flights for either business or pleasure are a key social group, even if they interact less directly with the technology. Furthermore, foundry workers are likely affected by the development of the alloys as they had to have been able to produce such an alloy on large scales. If key alloying ingredients were hazardous, it may have affected the environment for which these foundry workers existed in.

The next research question focuses on a separate aspect of aluminum: its recycling. Even though aluminum is the most common metal found in Earth's crust, it has only begun to be produced on an industrial scale within the last 150 years (Schlesinger, 2013). Aluminum begin to be used on a wide scale well after humans began utilizing copper, bronze and even steel. Why was it that the most common metal in Earth's crust took so long to be developed? One large problem facing the use of aluminum was its refinement from its natural ore: Bauxite. The process of refining bauxite into pure aluminum is difficult and very energy intensive (Donoghue et al., 2014). However, another large advantage of aluminum is its ability to be recycled without using a vast amount of energy. This is partially due to its low melting temperature and its general homogeneity of the material which allows it to melt and mix with other alloys well. The energy costs of producing primary aluminum (directly from processing bauxite ore) and secondary processing (from recycling of aluminum scraps) can be seen in Figure 2 (Schlesinger, 2013).

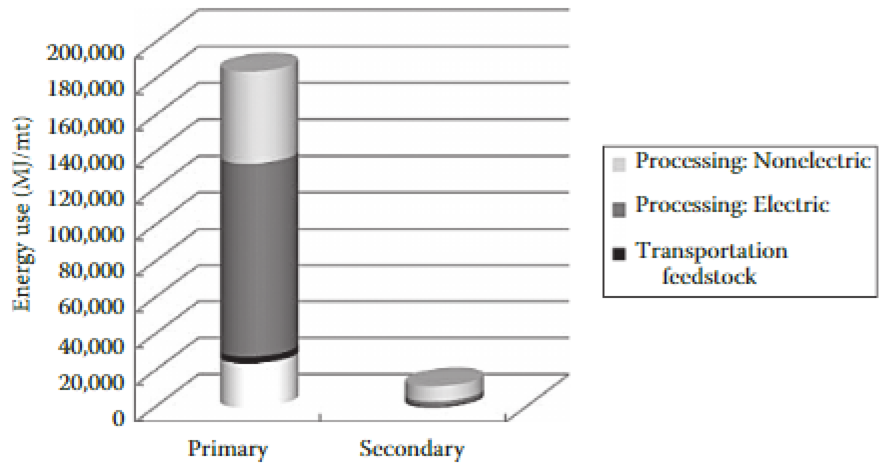

Figure 2. Demonstration of the different amounts of energy required to produce aluminum in megajoules per megaton of aluminum. The energies are also categorized into transportation and processing (Schlesinger, 2013).

Key social groups for the recycling of aluminum include environmental activists who often push for more recycling in general. Recycling center workers and general workers required by the infrastructure of recycling. Plastic companies or companies that utilize plastics in areas like single use water bottles are also key as the recycling needs often compete.

The proposed project timeline for this is as follows:

Fall semester

- Learn about STS methodology of SCOT – Sep 12
- Peer review of prospectus – Oct 12
- Produce annotated bibliography – Nov 18
- Submit final prospectus – Nov 25
- Present prospectus – Dec 5

Spring semester

- Evaluate historical developments of aluminum and its alloys – Feb
- Examine infrastructure of aluminum recycling and industrial alloy production – March
- Apply STS frameworks to the collected research – April
- Submit thesis and conclude STS study – May

Key Texts

The Smithsonian has published a collection of papers on the history of aluminum, edited by Chemello (Chemello et al., 2019). These papers do not touch directly on the social development of aluminum. However, it does go into detail about the history of aluminum with particular emphasis on the aviation industry. This is crucial to the thesis as in order to understand how social networks influence the development of a technology, its history must be understood first. The articles also go in depth about the properties of aluminum and especially highlight the corrosion reactions of aluminum, which may be useful information to better understand the appeal of using aluminum.

Schlesinger has written a textbook emphasizing the recycling process of aluminum along with a lot of the infrastructure in place to allow for the mass recycling of aluminum (Schlesinger, 2013). This is important since the infrastructure of recycling connects aluminum to many social groups and can help draw connection well into the development of aluminum.

An evaluation of the technopolitics of aluminum mining and its effect on the Amazonian quilombolas was done by Arregui (Arregui, 2015). This paper reveals the detrimental effects of aluminum mining on certain communities and social groups. Specifically, it is a case study of a social group known as the quilombolas, who are members of settlements originally established by escaped slaves in Brazil. The politics of aluminum mining affects the politics around recycling, as higher rates of aluminum recycling directly lower the demand on aluminum mining.

Alex Nading wrote a journal article on the recycling done in peri-urban Managua, the capital of Nicaragua (Nading, 2011). This reveals methods of non-industrial recycling as it was focused around more artisanal and small-scale recycling of aluminum. This article argues that the recycling of aluminum in these social groups was a necessary action as the metalworks sector nearly collapsed. Using a case study, Nading demonstrates the need for recycling and how it can affect different social groups. Especially as ore refining is not accessible to small forges and other businesses reliant on metals, it is important to understand how recycling can enable these groups.

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