Thesis Project Portfolio

American Institute of Aeronautics and Astronautics: Hybrid-Electric Regional Turboprop Design Competition

Conceptual Design of the Songbird-E

(Technical Report)

The Harmful Effects of Rare-Earth Mining: A Case Study of the Bayan Obo Rare-Earth Mine

(STS Research Paper)

An Undergraduate Thesis

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Executive Summary

In a world increasingly-concerned with the use of fossil fuels, industries that currently rely on them are seeking to shift towards renewable energy. The transportation industry, and more specifically, the aviation industry, contribute heavily to global carbon emissions. The transportation sector as a whole generating 37% of global carbon dioxide emissions, with the aviation industry contributing 2% of the total (International Energy Agency, 2022a, 2022b). Accordingly, the American Institute of Aeronautics (AIAA) has sought to help the aviation industry in this journey. One means of this has been by holding environmentally-conscious design challenges, with this year's request for proposals seeking hybrid-electric, regional, turboprop aircraft concepts. In fulfillment of our capstone project, my team is designing a concept named the *Songbird-E*, to fulfill the request. Future aviation technologies, especially electric motors and power plants, rely heavily on the use of rare-earth metals in their operation. In response to this, and the often-proposed solution that electric technologies are a panacea for issues of emissions and pollution, my STS research project seeks to conduct a case study of the Bayan Obo rare-earth mine in Bayan Obo, China. This mine is the largest of its kind in the world, containing more than 80% of China's reserves. Together, these two topics seek to explore and understand two different aspects of the electrification of the world.

For the technical portion of this project, a hybrid-electric, regional, turboprop aircraft has been designed. For the AIAA Design Competition, the main figure of merit is a reduction in block fuel burn, or the amount of fuel burned over a specific mission. Our proposed 2035 concept, the *Songbird-E*, claims that, by use of more efficient aerodynamics, future engine technologies, and lightweight systems and materials, block fuel burn can be reduced by more than 30%, significantly exceeding the design competition's minimum of 20%. There are many

untapped areas of potential in aircraft of this size, including adopting winglets, which are already used in many larger aircraft. The main benefit of hybrid-electric systems on aircraft is that they allow power to be diverted away from the fuselage, where the air is cleaner, and can be accelerated with less drag. We have taken advantage of this by placing electric motors close to the edge of each wing, powered by the same shaft that powers the interior engines. Battery technologies pose lots of issues for integration into aircraft, including safety, maintenance, and weight. Neither current nor projected battery technologies are feasible in this 12-year timeframe of design. Overall, this aircraft has been designed and comprehensively studied to put forth the best possible candidate for the 2023 AIAA Design Competition.

Electric motors and generators, such as those utilized in the *Songbird-E*, utilize a lot of rare-earth metals. Electric motors use about 5-6 times as much rare-earth metals as their internal combustion counterparts. There are currently many issues with this necessity in electric motors and technologies. By examining the Bayan Obo Mine in China, these issues are on full display. The mining process was allowed to continue unmitigated for the greater part of 50 years, with the first mine there opening in 1957 (NS Energy, 2020). The rare-earth process uses many toxic chemicals in its mining and early refinement processes. These chemicals have drastically affected the environment of the region, by food, water, and air. In turn, a once-flourishing farmland has become desolate, and a marginalized community of farmers has been made even more destitute. Not only has it had negative effects on the land, but the inhabitants of the region have shown substantial negative health effects, such as decreases in bone density (Liu et al., 2021). China's monopoly on the rare-earth market has also generated international disputes, one of which led to Japan, which was China's largest rare-earth consumer at the time, to be temporarily prohibited from purchasing these precious metals, due to a territorial dispute (ANI

News, 2023). These technologies are especially vital for shifting to electric technologies, but have lots of negative impacts on the health of people and the environment, as well as on international relations and the world.

These projects have both been largely successful. In regards to the technical project, we are confidently delivering a worthy product, one that has been investigated in-depth, and which there are few holes in its design. The design far and away exceeds the minimum block fuel burn set forth, much to the surprise of myself and my team. Achieving a 20% reduction was thought initially to be very difficult, if not impossible. By the use of improved aerodynamics and materials, we were able to exceed that reduction, before even incorporating our hybrid-electric propulsion system. The *Songbird-E* could use more investigation in the realm of aerodynamics, including computational fluid dynamics analysis, to determine the actual impact of enumerated aerodynamic benefits. As we have found substantial benefits in a hybrid-electric concept of this size, the importance of cleaner rare-earth mining processes, and a more ethical industry, is clearly emphasized. I was able to accomplish much of what I set out to do in this project, that is, showing how harmful rare-earth mining can be for the environment, and even exploring areas that I had not originally planned for, such as the political impacts. This project could use more primary sources. Interviews were scarce, likely due to fear of retaliation, and lack of public material that would incriminate China. More quantitative information would also help. Overall, I am very satisfied with the outcomes of both projects, and think they work well together as an investigation into the electrification of our world, and especially the transportation industry.

In the completion of this portfolio, I would first like to acknowledge and give great thanks to our Lord, Jesus Christ, and the intercession of the Blessed Virgin Mary. Without the many blessings the Lord has bestowed upon my life, I would not be here completing this degree.

All of this work is dedicated to them, for without them, nothing would be possible. I would also like to thank my loving fiancée, Dakota, for all of her love and support along the way. By means of this work and degree, I hope to be able to provide well for us, and God-willing, for a large family. I would also like to thank my family. I would like to thank my dad, Thomas, for his love and support. Though he was taken from us too soon, I would not be where I am today without his support. I would like to thank my mom, Karla, for all of her love and support throughout my schooling. Without her help and support, I would not have been able to accomplish all that I have. She has been, and continues to be, the force that ensures everything happens. Ad maiorem Dei gloriam!

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