DESIGN OF AN EFFICIENT, HYBRID ELECTRIC REGIONAL TURBOPROP

IMPACT OF LITHIUM MINING ON THE LOCAL POPULATIONS OF THE "LITHIUM TRIANGLE"

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering

By
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December 9, 2022

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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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General Research Question

How is the aviation industry moving towards a more sustainable future?

As a whole, the global aviation industry contributes about 2.1% of the total carbon dioxide emitted by humans. In 2019, this amounted to 915 million metric tons of carbon dioxide (*Facts & Figures*, n.d.). Air travel effects the climate in many other ways than just the emission of CO_2. Contrails and contrail-induced cirrus clouds trap infrared light, which causes a warming effect. The warming effect just from contrails and contrail-induced clouds exceeds the effect of all the CO_2 emitted ever by airplanes. Also, airplane engines exhaust nitrous oxides. These NOx gases also cause a warming effect (Overton, 2019). With the recent recognition of global warming as a major issue, and a push towards a cleaner future, the aviation industry must also contribute. As a result, in 2021, the US set a goal for the US aviation sector to achieve net-zero greenhouse gas emissions by 2050 (Shepardson, 2021). Because of this, engineers are turning towards sustainable aviation technologies, such as hybrid-electric aircraft.

Hybrid-electric aircraft are much like hybrid cars: part of the power they use comes from electricity. This electricity can be used in place of fuel, and as electricity can be generated from renewable or at least more efficient sources, hybrid electric aircraft are more environmentally friendly than their conventional counterparts. This, however, brings up the sustainability of the electric components necessary to run these hybrid aircraft. Many electrical components require toxic materials to function, such as rare earth metals and other metals. These materials must be mined or harvested, and this process can contribute to the climate crisis, such as from mining runoff or pollution from material refinement processes. Moreover, material extraction and refinement can affect local communities. These local communities must deal with exploitation by mining companies and the negative environmental effect of related industries. The sustainability of the aviation industry is not just based on aircraft themselves. The systems that support sustainable aviation must also be sustainable themselves.

Design of an Efficient, Hybrid Electric Regional Turboprop

How can a hybrid-electric turboprop aircraft be designed to be more fuel efficient than an existing conventional regional turboprop?

In the past 20 years, aerospace engineers have begun to shift their focus towards cleaner aircraft. One class of these cleaner aircraft are hybrid electric aircraft. These aircraft leverage electricity as well as conventional jet fuel for thrust production. Use of electricity helps increase the efficiency of these aircraft compared to their conventional counterparts. Firstly, on-board batteries can be charged on the runway, using electricity generated from the grid. Grid-generated electricity releases less carbon than burning jet fuel does. Also, when using electric motors, which are more efficient at transforming energy into thrust, the internal combustion engine can be run at optimal conditions (Xie et al., 2021). Hybrid electric aircraft can be more efficient than conventional aircraft, but there are still limitations to this technology. Design of an aircraft is already a very complicated process, with many variables, and so designing a more efficient hybrid aircraft is very challenging. However, if these hybrid aircraft replace conventional aircraft, it would dramatically increase the sustainability of the aviation sector.

There has been considerable research done into hybrid electric aircraft; however, there is a lack of viable designs for hybrid aircraft for use in industry. This project aims to create a viable hybrid turboprop design. One of the main focuses of research has been on the different types of hybrid electric architectures. The different architectures employ different ways of using electricity and combustion engines to produce thrust. Each different architecture has different weights, necessary components, and performance characteristics. The main architectures are parallel, series, and turboelectric. In parallel architecture, a battery, and a combustion engine work together to create thrust. In series, the combustion engine runs a generator, which powers a battery, which powers an electric motor. Turboelectric architecture is the same as series, but without a battery (Rendón et al., 2021). Battery technologies are one of the main design challenges for hybrid aircraft. Current batteries have low battery energy densities, meaning they do not carry much energy per unit mass. State of the art lithium-ion batteries have about 200 Wh/kg, while conventional fuel has a density of 13,000 Wh/kg. For this reason, one needs much more mass for the same amount of energy if using batteries (Voskuijl et al., 2018). To be capable of flight, aircraft must be as light as possible, so battery technology is a major factor in the lack of commercially available hybrid aircraft.

In this project, the team is tasked with designing such an aircraft, specifically a regional turboprop hybrid aircraft. This design must meet certain requirements set forth by the AIAA hybrid turboprop request for proposal. The main requirements state that this aircraft must be able to fly for 1000 nautical miles, seat 46-50 passengers, and most importantly, must leverage hybrid electric technology to decrease block fuel burn by 20% compared to a conventional turboprops (*AIAA Design Competitions*, n.d.). This design challenge serves to fulfill the need for regional, energy efficient turboprops. ATR, an aircraft manufacturing company, predicts that by 2041 there will be a need for about 2,450 new turboprops (*Turboprop Market Forecast 2022-2041*, n.d.). Clearly, there is a market for these efficient regional turboprops. Fulfilling this need with hybrid electric aircraft would help reduce emissions, aiding in the aviation industry to meet its goal of net-zero emissions by 2050.

To meet this goal, the team read the AIAA request for proposal thoroughly, to determine design drivers. The main drivers were determined to be the type of architecture employed, and degree of hybridization, meaning the number of batteries and hybrid electric components. Then, three main steps were established: First, a state-of-the-art review of the hybrid electric turboprop as a whole will be completed. This will identify potential technologies to include in the design. It will also determine the state of existing technologies, and improvements on them. Second, viable aircraft outer-mold designs, or 3-D models, must be created. These will be created through a modeling software called OpenVSP and must meet the AIAA requirements. These aircraft designs will then be sized to estimate aircraft and fuel weights. Third, trade studies on the main design drivers and other derived minor design factors will be run. These trade studies will determine optimal configurations of hybrid architectures, battery weights, and other factors. One of the main software used for these studies will be FLOPS (Flight Optimization System). Then, a single design will be considered. This single design will then go through further stages of iteration and improvement to reach a final design. This is an oversimplification, as most of the design work will be completed by adjusting the single design, and analyzing for various performance data to arrive at an optimal final design.

At the end of this project, a fully viable hybrid-electric aircraft concept will be created that meets all necessary requirements by the AIAA. This design will improve on current conventional turboprops in fuel efficiency and emissions. This not only serves to make this aircraft cheaper to run for airlines, but helps the aviation industry as a whole reach its goal of net-zero emissions by 2050. Currently, hybrid aircraft are mostly viable for smaller scale aircraft. However, this design could become the basis for larger aircraft, flying internationally, rather than regionally. In the future, the aviation industry could be dominated by eco-friendly, hybrid aircraft, based off work done in this project.

Impact of Lithium Mining on the Local Populations of the "Lithium Triangle"

What are the impacts of lithium mining in the "Lithium Triangle" of South America on local populations, and the associated implications?

A major component of a greener future is the lithium-ion battery. Used in laptops, phones, electric cars and electric aircraft, lithium-ion batteries are incredibly useful. But is the lithium-ion battery actually that sustainable? The so-called "Lithium Triangle" encompasses the massive lithium reserves found in South America. Made up of Argentina, Chile, and Bolivia, the Lithium Triangle contains over 75% of the world's lithium deposits. Demand for this lithium has increased by 8.9% annually (Ahmad, 2020). Therefore, the mining of lithium in this area is incredibly lucrative. However, this mining is led by transnational corporations, who negotiate with state and provincial governments, often ignoring the opinions of the local populations. This conflict between local populations and companies who want to exploit them for the natural resources they own happens all over the world; a notable example is rare earth metal mining in China. Fully understanding the situation in the Lithium Triangle will help explain each actor's wants and needs, and how to balance them in a sustainable manner: both environmentally and socially. For a green technology to be sustainable, like the hybrid electric aircraft, the entire system to build it must also be sustainable. A cleaner future cannot be based upon the exploitation of marginalized communities.

Background and Literature Review

In this sociotechnical system, there are three major actants: the transnational extraction companies, the provincial governments, and the affected local populations. These transnational companies extract lithium by different modes: non-negotiated, negotiated, and aborted extraction. Non-negotiated extraction is when the company makes minimal concessions to local stakeholders. In negotiated extraction, the local stakeholders can influence the process, allowing the local government and local communities to participate in regulation and governance. This type of extraction has two types: symmetrical and asymmetrical. In symmetrical negotiated extraction local stakeholders have a strong influence over the behavior of the company; in asymmetrical, local stakeholders have a weak influence. Aborted extraction is when the company withdraws its plans for a mining project (González & Snyder, 2021).

Another of the major players in the sociotechnical system of mining lithium are the provincial governments. In Argentina, power over the extraction of natural resources mostly sits with that provincial government. This provincial government, in conjunction with transnational corporations, is promoting the short-term benefits of lithium mining to the public. These short-term benefits, such as employment, are how the companies and the provincial governments legitimize lithium mining. The provincial government hopes to promote industrialization and economic growth through a rapid increase in lithium mining. However, this ignores the more negative, long-term effects of mining, such as a depleting water supply (Ortiz, 2021).

Lithium mining currently is not sustainable for the local populations. Lithium mining caused decreases in total stored water, while water consumption overall increased (Liu & Agusdinata, 2020). This is due to the actual process of lithium extraction. Lithium is extracted from briny groundwater. This water is allowed to evaporate, and lithium compounds are left behind. However, this process takes approximately 500,000 gallons of water for each ton of lithium. These lithium deposits are found in salt flats where water is very scarce. This has put extreme pressure on local populations who rely on this water for drinking and farming (Ahmad, 2020). The main positive of the mining industry is that it has produced many new jobs; however, these new jobs are often filled by long-distance laborers. In Salar de Atacama, Chile, only 18% of mining related laborers are locals. Some industries have increased the number of local laborers hired, including trade and public administration. These migratory workers can help boost the local economy. However, the major negative impacts are increasing water shortages and unequal negotiations with the companies (Liu & Agusdinata, 2020).

The local populations surrounding extraction sites have opposed these mining projects with varying success. In the Jujuy province in Argentina, locals claimed that the companies either did not consult with them, or that relevant information presented was unclear or even missing. Also, in some cases, provincial government officials were not present at these meetings. In Salinas Grandes, Argentina, companies again failed to communicate relevant information to the locals. However, in this case, locals drafted a community protocol to set guidelines for mining and negotiations. This caused mining permits in the area to be suspended (Marchegiani et al., 2020). These cases illustrate the issue present in the extraction of valuable materials. Companies are primarily focused on profits. They want minimal costs to extract lithium to produce batteries. Provincial governments want to promote trade with these companies, often at the cost of local populations. These local populations often deal with the brunt of the consequences, with minimal input, especially unorganized, under-represented, or marginalized communities. Barandiraran posits that recently, these lithium extraction projects have started to shift from merely extraction, towards industrialization, exporting industrial goods instead of raw materials. However, he highlights the lack of research on the ramifications of this shift, and the sociotechnical system as a whole (Barandiarán, 2019). This research project aims to target this gap in knowledge, to analyze this sociotechnical system further to determine how best to make these extraction systems sustainable for all parties.

Research Methods

For my research, I will perform a content analysis on different mining projects in the Lithium Triangle. To do this, I will collect company reports from companies planning or involved in current projects. I will collect the logs of negotiation meetings between lithium mining companies and the local representatives. I will also record sources of local support or opposition, such as newspaper articles, essays, or speeches. From these, I will determine how companies and the local communities negotiated terms for extraction, and categorize how local populations responded and opposed mining projects. I will also record government briefs relating to mining projects and records of government action within these projects, to also analyze the provincial governments' involvement in these negotiations, in both manner and extent.

Conclusion

The purpose of the STS research is to analyze the sociotechnical system surrounding lithium extraction in the Lithium Triangle of South America. This analysis can highlight successful methods of lithium extraction, methods that meet the demand for lithium, but do not infringe upon the rights of local populations. These methods can be applied to other systems of raw material extraction to ensure that extraction is sustainable for the communities around them. In the specific case of lithium, this lithium is needed by batteries to be employed by the hybrid electric aircraft of tomorrow. Through this technical project, a viable, efficient, hybrid electric turboprop will be designed. This hybrid turboprop will outperform the conventional turboprop in terms of fuel burn and overall emissions. This will help demonstrate that hybrid aircraft can be used to reduce emissions of the aviation industry as a whole. This design can be used as a building block, to serve as a basis for a transition to a more efficient and sustainable industry. That is the overarching goal of this paper: to determine the sustainability of the entire aviation sector. For an entire industry to be sustainable, that means all technologies, actants and materials must be sustainable. This paper analyzes the industry from two distinct sides: the technical and the social. To reach the aviation industry goal of zero-net emissions by 2050, not only the technologies but also the supply lines of those technologies must be sustainable. A system built on exploitation of others is not sustainable at all.

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