**AIAA 2022-2023 Undergraduate Hybrid-Electric Regional Turboprop**

# Aviation and the Environment: An Analysis of the Environmental Implications of Aviation and the Interplay Between Society and Practical Mitigation Strategies

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By
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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

As society has begun to place a growing emphasis on sustainability and the environmental implications of our day to day operations, few industries have faced greater scrutiny than the aviation industry. As reported by the EPA, commercial airplanes and large business jets contribute 10 percent of U.S transportation emissions and account for 3 percent of the nation's total greenhouse gas (GHG) emissions (Overton, 2022). In terms of the global $CO_2$ emissions, aviation contributed 2.4 percent of the total in 2018. Though this contribution may seem insignificant, if global commercial aviation had been its own country in the 2019 GHG emissions standings, the industry would rank number 6 in the world (Overton, 2022). Thus the significant scrutiny pertaining to environmental sustainability that the aviation industry has found itself under is not without warrant. As a result, extensive research has been conducted into the practicality of many proposed mitigation strategies for the environmental implications of the aviation industry. This is the topic of concern for both my technical paper and my STS research paper.

My technical paper will focus on the design of a hybrid-electric regional turboprop aircraft with an entry into service date of 2035. Analysis has shown that in terms of minimizing environmental impact, regional turboprops are superior to regional jets. This is largely due to the higher fuel efficiency of regional turboprops relative to regional jets (Babikian et al., 2002). Thus the design of improved regional turboprops that could leverage hybrid-electric propulsion highlights a specific mitigation strategy pertaining to the environmental implications of the aviation industry. My STS research paper will explore the role a changing society, comprising myriad relevant social groups, plays in the exploration of potential mitigation strategies. It will then proceed with a general analysis of these practical mitigation strategies through a sociotechnical lens to address environmental sustainability.

## Technical Topic

The design of a hybrid-electric regional turboprop highlights a specific potential mitigation strategy for the harmful effects of aviation on the environment as $CO_2$ emissions have been shown to be considerably lower for regional turboprops relative to regional jets. For instance, if regional jet capacity on routes up to 500 nautical miles (nmi) in the U.S. were replaced by turboprops, there would be an immediate 28% reduction in $CO_2$ emissions (Turboprop Market Forecast 2022-2041, 2021). Though both regional jets and regional turboprops operate over comparable flight distances, the key difference between them is their use of propulsion: regional jets utilize jet engines whereas regional turboprops employ turboprop engines.

Analysis from researchers working in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology, a reputable source in the field of aeronautical engineering, has shown that an increased fuel efficiency is derived from the use of turboprop engines in regional aviation relative to jet engines (Babikian et al., 2002). With the promise of further emission reduction from the implementation of hybrid-electric propulsion, the potential for this type of aircraft with regards to environmental sustainability is immense. Consequently, a key goal for this design as outlined by the AIAA RFP is to reduce the block fuel on a 500 nmi mission by 20+% vs current turboprops in addition to an overall reduction in harmful emissions such as $CO_2$, NOX, soot, etc. (American Institute of Aeronautics and Astronautics, 2022).

To approach this design, I, along with my design team, will undergo the full conceptual design process for an aircraft including sizing, configuration, etc. in order to produce a feasible design with an entry into service date of 2035. By researching current regional turboprops with similar mission objectives, we will apply a similarity analysis in order to inform our initial selection of key design characteristics. This will be done in conjunction with the system requirements review (SRR), which provides an extensive analysis of the RFP in order to assess all important design parameters and their relationships. These analyses will subsequently inform the concept ideation phase, where I and each of my team members will produce aircraft configuration concepts in order to select the three most promising designs to begin aircraft sizing. Once we have closed on a design, we will employ the use of trade studies to explore the sensitivities of our design to different factors in order to determine the optimal design and its dependencies.

One significant design choice that will need to be considered is the level of hybridization and architecture used for the electric propulsion system. Substantial research has gone towards the assessment of different hybrid-electric architectures, particularly the parallel and series hybrid schemes. The distinction between the two, as discussed in a validated study analyzing current hybrid-electric aircraft sizing methods, is as follows: In the parallel scheme, a gas turbine works in conjunction with an electric motor to produce thrust whereas in the series scheme, the gas turbine generates electricity for the electric motor, which subsequently produces the thrust (Finger et al., 2020). Each scheme has its own costs and benefits that my team and I will have to consider in the design process.

## STS Topic

Though the current design of commercial aircraft has gained substantial technological momentum within our society, it is widely accepted that the current industry model contributes greatly to the issue of climate change. As society begins to value environmental sustainability with a greater emphasis, considerable pressure has been placed on the aviation industry to produce aircraft with greater consideration of their environmental implications. To address sustainability concerns, analysis has indicated that substantial reductions in emissions will require the introduction of new and radical technologies (Lee et al., 2009).

While I agree with this conclusion, I will argue through my research that even the most technical of mitigation strategies must be implemented within and thus subsequently will be dependent upon a society comprising myriad relevant social groups, each with differing values and perspectives. Illustrating this interdependency between the technical mitigation strategies and society is a current push for the development of policy initiatives aimed at constructing a more environmentally conscientious industry. The development of a sustainable aviation industry, however, has become a contested issue, leading to a growing and ongoing debate between various social groups over which mitigation strategies, if any, should be employed. As a result of the contested nature of sustainable aviation, it has been concluded that the reframing of aviation policy must by necessity be fraught with political and technical difficulties that merit a wider dialogue to address a complex set of interconnected political and social challenges (Budd et al., 2013).

To reinforce this conclusion, my research will utilize the framework of the social construction of technology (SCOT) to explore how the values of various groups in society including but not limited to the aviation industry, environmentalists, passengers, and governmental stakeholders have both contributed to the ongoing debate regarding the issue of sustainable aviation and have begun to push the current design of aircraft out of closure and towards new and innovative designs that emphasize environmental sustainability. In addition, I will employ a sociotechnical analysis of the current flexibility in mitigation strategies being pursued to assess the practicality and consequences of the primary strategies being considered based upon the values of these social groups.

In the consideration of policy strategies pertaining to environmental sustainability, two theoretical perspectives have emerged: the perspectives of green-growth and degrowth. The key distinction between these two perspectives is that green growthists believe that economic growth and environmental protection are compatible whereas degrowthists believe the two are incompatible. Though research through critical social theory has suggested that degrowth has a stronger normative justification than green growth, the most widely accepted solution continues to be green growth (Sandberg et al., 2019). My research will analyze this conclusion in the consideration of the social construction of sustainable aviation. I will assess whether this emphasis on green growth has dominated the exploration of practical mitigation strategies in aviation, giving groups such as the aviation industry, which values strategies such as sustainable aviation fuels (SAF) that allow for industry growth with minimal economic impact over policies such as green taxes, considerable power in the ongoing debate.

As discussed in both a paper for the ScienceDirect Energy journal and a paper for the Frontiers in Energy Research journal, there is great potential for the development of SAF in the mitigation of harmful emissions resulting from the aviation industry (Kramer et al., 2022; Yilmaz & Atmanli, 2017). However, though both journals are established and reputable in the field of energy research, conclusions pertaining to the practicality and technological readiness level

(TRL) of this particular mitigation strategy are not universal. For instance, as discussed briefly in Rathore et al. (2020), the current high cost associated with SAF makes it unacceptable for the developing Indian aviation industry. Instead, Rathore et al. (2020) argues that though government stakeholders in countries with developing economies that rely heavily on their respective aviation industries tend to be apprehensive towards strategies such as the implementation of carbon taxes, concerns that these measures would adversely affect growth are far-fetched. Nonetheless, representatives from both the aviation industry and developing economies tend to view policy initiatives such as international taxes often championed by countries with more developed economies with concern.

This distinction between government stakeholders representing developed versus developing economies is an example of the complexity inherent to the ongoing debate. My research will aim to consider both these differing perspectives and those related to other strategies and relevant groups in order to demonstrate further the complexity within the interplay between society and the establishment of practical mitigation strategies in aviation.

## Conclusion

Concluding my research will be the presentation of both a technical paper and an STS research paper highlighting the topics studied. My technical paper will focus on the conceptual design of a hybrid-electric regional turboprop aircraft with an entry into service date of 2035, explaining the process undergone by my design team as we closed on a final design. My STS research paper will present the findings of my research into both the role a changing society plays in the exploration of mitigation strategies and an analysis of these mitigation strategies through a sociotechnical lens that addresses environmental sustainability. In addressing the topic of sustainable aviation, my research seeks to yield the following: First, by presenting the design of a hybrid-electric regional turboprop, an increased understanding of the feasibility, design requirements, and trade-offs associated with this particular mitigation strategy shall be established. Second, an exploration of other mitigation strategies under consideration shall yield a more comprehensive understanding of the practicality and consequences of each.

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