Solar-Powered Autonomous Reconnaissance Craft (SPARC) Aircraft Design
(Technical Paper)

The Aviation Industry's Transition to a Sustainable Future,
A Multi-Level Perspective Analysis
(STS Paper)

A **Thesis Prospectus** in STS 4500
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By
Adam Snyder

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Technical Team Members:

Miles Beam
Victoria Camacho
Michael Chou
Larry Egalla
Graham Guerette
Christopher Recupero
James Richard
Declan Long
Nathan Ong
Defne Savas
Muhammad Vasal

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.

ADVISORS:

Dr. Joshua Earle, Department of Engineering and Society

Dr. Aldo Gargiulo, Department of Mechanical and Aerospace Engineering

Introduction

Given the detrimental effects of global climate change, it becomes increasingly relevant to scrutinize our society's largest contributors to carbon emissions. Cutting-edge technologies being developed today can enable aircraft to reduce their reliance on fossil fuels and manage the aviation industry's carbon footprint in the coming decades. In my thesis, I will be delivering a technical design report for a highly capable aircraft which relies on solar power and an STS research paper which assesses the aviation industry's transition to sustainable practices.

For the technical portion of this project, my senior capstone team is designing a solar powered autonomous aircraft, coined SPARC. This fixed-wing plane will be designed to be unmanned and entirely reliant on solar power for propulsion. This aircraft will be unique in its modular design, for which the bulk of the fuselage will be easily interchangeable in order to support a vast variety of instrumentation as its payload. Its lightweight design will also allow it to fly for extended durations. Primary uses of this aircraft might include reconnaissance or research over remote regions, or aerial surveillance over an area for several hours or days. The simplicity and adaptability of the aircraft make it inexpensive and unique compared to vehicles with similar missions, such as satellites and crewed aircraft, and it is able to operate without any carbon emissions. By choosing a project which is both marketable and sustainable, we hope to encourage future research into solar-powered aerospace technologies.

In my STS project, I will focus on the commercial aviation industry's commitment and progress toward an environmentally sustainable future. There are two questions central to my research: How can modern innovations contribute to reducing carbon emissions in the aviation industry? How do different institutions within the aviation industry influence the development and popularization of these new technologies? This analysis is particularly relevant because commercial flights are estimated to contribute 2-3% of all United States carbon emissions (US EPA, 2019), and the FAA has set a goal for the entire U.S. aviation sector to produce net zero greenhouse gas (GHG) emissions by 2050 (Williams, 2021). I plan to employ a Multi-Level Perspective analysis in order to address these questions and assess the state of the aviation industry.

Technical Project

Problem/Significance:

Aviation is a major contributor to greenhouse gas emissions, and finding ways to reduce aviation's carbon footprint in an ever-growing industry is critical for long term sustainability. While strides have been made with hybrid (electric/combustion) engines and Sustainable Aviation Fuel (SAF) technologies, these solutions alone remain insufficient for achieving full decarbonization and zero emissions in aviation. Advances in traditional propulsion technology have allowed for more efficient engines; however, jet powered and piston aircraft still rely on traditional fossil fuels (Clark & Mouawad, 2010). Fossil fuels emissions, such as CO_2, NOx, and unburned hydrocarbons like CO, compound aviation's environmental impact. At high altitudes, the heat and exhaust from the engines also produce contrail tail cirrus clouds, which trap heat and contribute to rising surface temperatures (Lee et al., 2021).

Solar-powered aircraft offer a potential solution to reduce aviation emissions by using solar energy for propulsion. Advances in solar energy capture, lightweight materials, and innovative aerodynamic designs suggest that decarbonization through solar-powered aviation is feasible (Güntürkün & Çınar, 2021). However, substantial physical and technical challenges, such as limited energy density and range, currently prevent these technologies from scaling up to full-size, commercial applications.

This research focuses on developing a solar-powered, autonomous aircraft specifically designed for autonomous missions rather than commercial transport. By targeting an unmanned application, we address a more achievable domain for solar-powered flight, as smaller, lighter aircraft have lower power and endurance requirements. This goal represents a stepping stone that will drive continued innovation in sustainable aviation technology.

Objective of the research:

The goal of this project is to design and build a highly modular, adaptable, and autonomous solar-powered aircraft capable of being customized for a wide range of mission profiles. The project is titled SPARC, which stands for Solar Powered Autonomous Reconnaissance Craft. Its flexible architecture should allow for seamless integration of various payloads and sensors, enabling high-endurance, continuous operation for days or weeks on end. Suggested uses include military and civilian surveillance or imaging, as well as exploration missions across diverse environments. As sources of inspiration for our aircraft, the Solar Impulse II and Airbus Zephyr concept represent the most recent developments in solar powered flight, with the Solar Impulse II having conducted the first flight around the world powered solely by solar energy (Solar Impulse Foundation). We will use innovative techniques for system design and cutting-edge, light-weight materials for the aircraft, making it most suitable to fulfill its mission requirements. Additional objectives of our project include designing our aircraft to fit current market needs through its highly modular payload bay design, allowing for the incorporation of various kinds of equipment depending on mission needs. Secondly, the aircraft will push the boundaries of solar panel energy harvesting technology by maintaining continuous operation with at least 12 hours of daylight flight. Finally, we intend to develop our aircraft to carry out flight phases autonomously with limited human input. By fulfilling these objectives, we intend to demonstrate that undergraduate students are capable of designing and building the next generation of aircraft, and we hope to popularize the use of current solar panel and energy storage technology in aerospace applications.

Our primary deliverable for the Spring semester is to complete a Final Design Review of the Solar-Powered Autonomous Reconnaissance Craft (SPARC). In this review, we will report our findings for the entire project, beginning with our mission objectives and conceptual designs all the way through a detailed final vehicle design. This report will include various studies, such as structural and stability analyses and a detailed mission concept of operations to prove aircraft feasibility and establish overall performance metrics.

Secondly, we intend to apply for funding to construct a physical subscale model of the aircraft which is capable of sustained flight and will act as a proof of concept of the conceptual aircraft. This physical model will be constructed and first flown during the Spring 2025 semester. The goal of the model is to demonstrate static and dynamic stability, controllability, landing and takeoff systems, propulsion performance, and modularity of the payload bay. We intend for the aircraft to be a proof of concept that will spark further development of the SPARC aircraft design.

Short of receiving necessary funding to construct an operational subscale model, our baseline objective for the Spring 2025 semester is to perform benchtop tests on physical components to demonstrate our concept's feasibility. This includes the construction and testing of a system of solar panels in conjunction with a battery power storage unit as well as a demonstration of our ability to power propulsive motors, servos, and communication hardware with the supply system. We intend to experimentally simulate day- and nighttime operations and control our avionics system remotely in both modes of power supply, adhering as closely to our conceptual aircraft's true power budget as our funding will allow. These benchtop tests will be instrumental in our trajectory toward a working model, whether we acquire additional funding or otherwise. We have every intention of proceeding from benchtop tests to the fabrication of a subscale aerobody where we can integrate the components; however, the demonstrated viability of the components themselves will serve as a minimum metric of success.

Available Resources:

In order to fulfill the overall objectives of the project, we intend to use resources openly available to undergraduate Aerospace Engineers at the University of Virginia. This includes stability analysis software, computer aided design software, and Computational Fluid Dynamics software to design a conceptual aircraft that fits our mission requirements. The stability and conceptual design software used includes XFLR5 and Open VSP. The computer aided design software includes Autodesk Inventor 2024 and Solidworks 3D CAD, which provide design and finite element analysis (FEA) capabilities for aerostructure development. Ansys Fluent will also be used to analyze the aerodynamics of the aerobody structure and optimize key aspects of aircraft performance such as lift, drag, and material selection.

STS Project

Introduction:

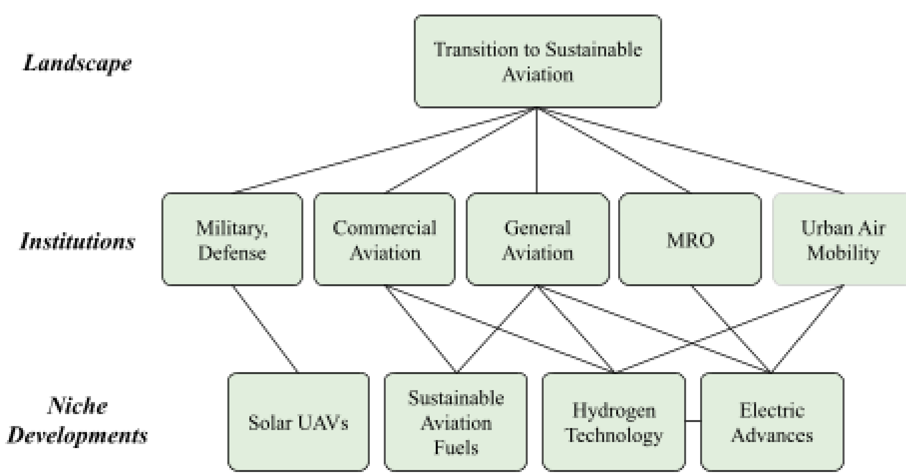
In my research, I will be examining a variety of cutting-edge aviation technologies which are advancing the industry toward sustainable flight. I am aiming to determine what today's sustainable flight technologies are truly capable of and then asking how effectively these technologies are being employed throughout the industry to advance sustainable practices. Numerous companies and agencies within the aviation industry publicize their sustainability goals, and I intend to assess the feasibility of these goals and how close or far away they are from being achieved.

While these questions are relevant to all of us affected by a changing climate, it is those within today's aviation industry who are central to these questions. The FAA, for one, is an essential group in this research, as they direct government policy surrounding aviation. Also crucial to this study are the large aircraft producers, such as Boeing and Airbus, as well as jet engine companies such as CFM International, Pratt & Whitney, Rolls Royce, and General Electric. Many others are relevant to this research, as they are responsible for developing the niche technologies. Some of which include defense contractors, eVTOL companies, SAF manufacturers, and experts in propulsion and electrical power.

Research Methods and Framework:

Most of my research will be based on a foundation of literature, as others before me have researched the technologies that I hope to examine. My research will be novel in incorporating these technologies into a comprehensive review of the industry by discussing how these technologies influence relevant socio-technical institutions. This is made possible by the use of the Multi-Level Perspective (MLP) STS framework, as this structure will guide my research and allow me to comprehensively assess this large scale transition.

My methods of analysis are centered around the MLP framework. This framework provides a way to analyze broad transitions in a socio-technical landscape, in which the system is broken down into specific socio-technical institutions and niche technological developments (Deviney et al., 2023). To analyze the transition in the U.S. Aviation Sector toward sustainable flight, I've outlined an MLP framework. Key institutions at play include the military and defense sector, commercial aviation, general aviation, and aircraft maintenance-repair-overhaul (MRO). Another institution which could be defined for its relevance to sustainable technologies is the urban air mobility industry. This is a new sector of aviation, yet to establish itself as a foundational institution in the industry, but it is the focus of many modern aviation startups and aviation market research (Cohen et al., 2021). My framework also includes technologies such as solar UAVs, sustainable aviation fuels (SAFs), hydrogen technologies, and advances in electric power storage and efficiency. While myriad technologies are being developed now, I chose to focus on these developments for their relevance to environmentally sustainable flight. This framework is outlined in the diagram below:



Thesis Planning:

This prospectus outlines my objectives for my thesis paper, which I will complete by May, 2025. To reach this goal, I will conduct research to analyze these niche technologies and their contributions to aviation institutions within the MLP framework. I will conduct my research in the coming months, starting now by collecting resources that discuss sustainable technology developments and existing institutions which comprise the aviation industry. In January, I will transition to narrowing down my sources, identifying key findings that will be central to my thesis arguments. My research will conclude in February, 2025, allowing time for me to synthesize this research into a thesis paper by May.

Numerous texts will provide the foundation for my research. So far, I have relied on Deviney, 2023 as a resource for understanding the Multi-Level Perspective (MLP) framework. Deviney argues that technology evolves with societal needs, and that the MLP was developed to examine such technological evolutions and their adoption by different socio-technical levels in the technological landscape. I have also used large-scale aviation analysis such as Lohawala and Wen, 2024, and Jensen et al., 2023, as resources for planning my thesis. Lohala and Wen analyze a variety of sustainable flight technologies, concluding that several challenges emerge alongside these technologies and further research and policy change are necessary for such technologies to become mainstream. Jensen illustrates a possible route to achieving net-zero emissions by 2050, with the majority of emission reduction coming from SAF scale-up and more reductions coming from modern aircraft designs with increased efficiency. Both reports identify steep challenges to move from the current state to a sustainable future, leaning heavily on SAF as a solution as this can be incorporated into existing air travel infrastructure. I will dive deeper into the technological analyses and discussions in these two reports as the next step in my research.

For further research, I plan to select at least one key academic publication for each institution and niche development within my framework. For example, for my research into solar technology, I will look to Safyanu, 2018, as this publication titled *Review of Photovoltaic Cells for Solar-Powered Aircraft Applications* gives excellent data on the state of various photovoltaic cell technologies and then discusses the applications of these technologies in past or future aircraft. Similar resources will be selected for SAF, hydrogen, and electric technology research for aircraft applications.

Conclusion

As described in this prospectus, I will be producing a Technical Design Review of an aircraft as well as an STS research paper as separate components of my thesis. My senior capstone team is designing a solar-powered, autonomous aircraft which will further the state of current aircraft technology by pushing the limits of solar-powered flight endurance and providing a multi-mission capable aircraft with a modular aircraft. These are a unique combination of assets in today's aviation sector and will be capable of fast and inexpensive production compared to other multi-mission aircraft. I am serving as the Aircraft Systems Team Lead, focusing on designing the aircraft such that it is stable, maneuverable, and capable of carrying out missions as required. In my STS research paper, I will be using a Multi-Level Perspective framework to inspect the aviation industry's transition toward sustainability. I will analyze the capabilities of new technologies at the micro-level as well as changes in the institutions which make up the industry at the meso-level in order to better understand the macro-level transformation. As a whole, this project aims to enhance my understanding of aircraft design as well as the aviation industry while upholding values of environmental sustainability.

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