Project Atlas

Net-Zero by 2050: An Examination of Sustainable Aviation

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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

“Got on board a westbound 747 / Didn't think before deciding what to do”(Albert Hammond). In today's world, this lyric from the 1972 hit song, *It Never Rains in Southern California*, has taken on new meaning. According to an article in the New York Times, “a small, yet growing, number of travelers… are giving up flying because of its impact on the climate” (Kamin). In 2024, less people are willing to hop on a 747 without thoroughly examining the consequences. For some, air travel is being viewed less and less as an escape, and more as a dangerous experiment leading to a point of no return in the climate crisis.

When Boeing introduced the 707 in 1958, a new age of aviation had commenced. Air travel began to permeate pop culture. Perhaps coined best by Frank Sinatra's hit song “Come Fly With Me,” people all over the world were ready to “glide, starry eyed” to exotic lands. The Jet Age had started. The world was shrinking. Flying was suddenly fashionable and highly desirable but not yet accessible for the masses. However, as the desire for air travel grew in the hearts of common people everywhere, engine technology also rapidly advanced. High-bypass ratio turbofan engines opened up an entirely new realm of possibilities for airframes. Boeing capitalized on this new technology and released a clean sheet design that would define an era. In 1970, Boeing entered into service the 747, the world's first “Jumbo-jet.” As noted by a Boeing engineer at the time, “The public was so taken by the 747 that, despite the recession, our sales picked up as more and more airlines jumped on the bandwagon” (Sutter 204). Sutter describes passengers stepping onto the 747 for the first time as being stunned with amazement. There was a palpable awe when it came to this plane, and it is still known today as the “queen of the skies.” These new planes were luxurious, spacious, and were radically cheaper to operate per seat than any plane before. Movies, music, and television were littered with references and images of both the 707 and the 747. All of these factors combined to create a rapidly growing industry. To this day, demand for air travel has continually increased and demand is projected to continue to grow in the coming years (Rutherford). Dreams of a more connected world have been achieved, but not without alarming side effects. Along with the rise in air travel, greenhouse gas (GHG) emissions, temperatures, and natural disasters have all increased at disconcertingly fast rates.

My technical project is focused on the design and manufacturing of a rocket engine. As with the 747, new engines created an entirely new realm of possibilities. Currently many companies are starting to examine the possibility of commercial space travel and/or intercontinental travel with the use of rockets. If a major jump in engine technology does occur, engineers will also need to consider the environmental impacts of another aviation revolution. My technical project will focus particularly on hybrid rocket engines. Hybrid rocket engines represent the safest means of rocket propulsion but face many limitations. Most prominently, the most efficient designs require complex geometries that are prohibitively expensive to manufacture. This project aims to alleviate these issues with hybrid rocket engines by leveraging additive manufacturing.

The STS portion of this paper focuses on sustainable commercial aviation and the regulations, technologies, and cultural forces involved in achieving net-zero carbon emissions by 2050. Looking ahead to this goal, society is also on the verge of a major revolution in space travel. Examining rocket engine technology in the broader context of commercial aviation will be an important part of the STS paper.

Project Atlas

The technical section of this paper will consist of the design and manufacturing of a hybrid rocket engine. Hybrid rocket engines get their name from having a solid fuel and a liquid oxidizer. Traditionally most research and development has been dedicated to solid rocket engines and liquid rocket engines. These engines tend to be more scalable and more efficient. However, this project will benefit from some key attributes of hybrid rocket engines. By using a solid fuel grain and liquid oxidizer with minimal plumbing, hybrid rocket motors combine the safety of liquid rocket motors with the simplicity of solid rocket motors (Sutton, G. P. and Biblarz, O.). Limiting factors in the development of hybrid rocket engines are the expense of manufacturing complex injector and fuel grain geometries. To optimize combustion, these parameters need to be carefully adjusted. Recent advances in additive manufacturing technology have made it possible to create complex designs at a low cost.

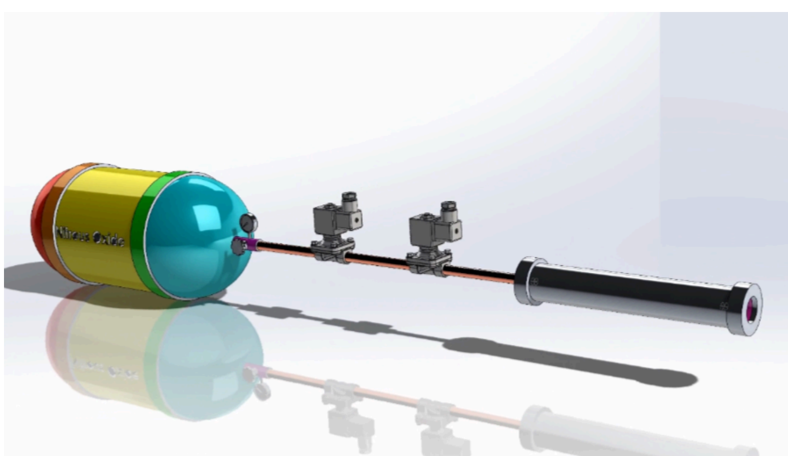

Figure 1. Hybrid Rocket Engine Assembly

The major components and subsystems are shown above in Figure 1. On the left is the oxidizer tank. This will be pressurized to about 750 psi and will contain Nitrous Oxide. From this tank, oxidizer will enter two valves (for redundancy), where it will then enter the injector and finally the combustion chamber. Once the oxidizer has entered through the nozzle into the combustion chamber, a charge will start the combustion reaction and the solid fuel grain and oxidizer will combust. As combustion occurs, exhaust gasses will be accelerated through a nozzle, and create an equal and opposite reaction that will generate thrust. Not shown in the assembly above will be a test stand to secure the motor and to collect data on the firing of the engine.

This project will allow UVA undergraduates to explore the development of rocket engines in a safe manner. As seen in the case of the 747, new engines predated the development of such a transformative aircraft. The goal of this project in conjunction with this paper will be to explore new rocket engine technologies while also considering how aviation as a whole needs to change to be more sustainable.

Net-Zero by 2050: An Examination of Sustainable Aviation

NASA administrator Bill Nelson said, “Science leaves no room for doubt: climate change is the existential threat of our time.” In the last decade, the earth has experienced 8 of the 10 hottest years in recorded history. Sea ice is melting and natural disasters are becoming more severe and more common (Greene). Concurrently, commercial aviation is expanding very quickly. Conservative estimates suggest aviation accounts for 2-3% of the total CO2 emissions. Although planes are becoming more efficient, these advancements are currently outpaced by growing air travel demand. According to a report on aviation by the International Law Commission, “CO2 emissions will be almost twice as high in 2030 compared to 2002”(Romera).

In light of this concerning information, governments all around the world have decided to introduce regulations on aviation. This paper will focus on the United States and the regulatory and technological challenges to creating a greener aviation industry. According to a government initiative released by Transportation Secretary Pete Buttigieg at the United Nations Climate Change Conference in 2021, the United States has decided on a goal of Net-Zero GHG Emissions from the U.S. Aviation Sector by 2050. This encompasses life cycle carbon dioxide, nitrous oxide, and methane emissions (FAA). This is a bold goal that will require participation from the general public, government, and industry to be achieved. The international council on clean transportation (ICCT) has detailed four possible scenarios and their potential impacts on achieving this goal. The first scenario is business as usual. This involves no changes to current strategies. The second scenario is action, defined as capping aviation emissions at 2019 levels. The third scenario is transformation, defined as coordinated efforts to move from fossil fuels by 2035 and halve 2019 emissions levels by 2050. Finally, the fourth scenario is called breakthrough, defined as, “early, aggressive, sustained government intervention that triggers widespread investments in zero carbon aircraft and fuels, peaking fossil fuel use in 2025 and zeroing it out by 2050” (Rutherford). This paper will examine the strategies laid out by the US government and by industry and how they fit into these different scenarios. Evidently, to achieve the goal of Net-zero by 2050, strong action needs to be taken.

Technologies

There are many technologies currently being developed that will be critical to the aviation sector’s success in achieving the goal of Net-zero by 2050. Some of these are very promising, while others face serious headwinds and/or will not be effective in creating a greener industry.

Electric, Hybrid-Electric, and Hydrogen Planes

Industry has been very clear about the challenges electric, hybrid-electric, and hydrogen planes are facing. Boeing's Chief Sustainability Officer stated, "We can't count on hydrogen-powered commercial flights before 2050" (Raymond). Hydrogen has many challenges. To start, it needs to be stored at cryogenic temperatures. It also is far less energy dense when compared to traditional jet fuels. This means larger tanks are needed to be able to fly the same distances. Additionally, hydrogen atoms are so small that they have many undesirable effects on the containers they are stored in. Furthermore, most hydrogen today is created with the use of fossil fuels. Finally, because of its low energy density, hydrogen is not suitable for long haul flights. According to Boeing, "flights over 1000 miles account for 80% of the industry's emissions"(Raymond). In other words, the routes that impact the environment the most will not be able to be flown by any hydrogen aircraft in the near future. Airbus has also scrapped plans to create a hydrogen powered aircraft citing the same challenges (Rutherford). Unfortunately electric airplanes are facing the same obstacles. Poor energy density and fossil fuel use in production limit electric planes's efficacy in helping achieve the goal of Net-zero by 2050. Beyond issues with the technology, Boeing and Airbus both face massive airplane backlogs thousands of aircraft long. Supply chain struggles and production issues plague both companies. Even if the technology was available today, it is unclear whether either company is positioned to mass produce a new airframe. As it stands today, hydrogen and electric technologies are far from large-scale implementation and will need serious government incentives to be developed.

Advanced Conventional Aircraft

Advanced Conventional Aircraft are new planes designed to burn traditional jet fuel. This technology will face the least headwind. Both Boeing and Airbus are designing new aircraft that will use traditional jet fuel but will be about 30% more efficient than current aircraft (Rutherford). Because higher efficiency means more profit for airlines, the industry is already primed to develop aircraft like these. Such designs will help, but are not the final answer in achieving net-zero by 2050.

Sustainable Aviation Fuel

Sustainable aviation fuel (SAF) is perhaps the most promising technology in this sector. The fuel used in nearly all aircraft today is known as JET A-1. As noted by Buse in his book on SAF, “JET A-1 is the ultimate aviation fuel. Not only in terms of its fuel properties, which are perfectly suited to modern jet engine design, but also in terms of a global supply chain that has been optimized over the past 60 years” (Buse 13). Sustainable aviation fuel will leverage the advantages of JET A-1 without the environmental impacts. SAF is designed to be able to be used in aircraft today without modification. SAF mimics Jet-A1 but is made from sustainable materials rather than fossil fuels. From a technical standpoint, this is an incredible breakthrough. However, there are still challenges with implementation. Mainly, Jet A-1 made from sustainable sources is far more expensive than JET A-1 made from fossil fuels. Without serious government incentives it is unlikely airlines will be inclined to take advantage of SAF.

Conclusion

The technical deliverable for my capstone project will be a proof-of-concept for future student rocketry projects at UVA. Future students will be able to build off of this foundation to examine the technologies that will power the aircraft of tomorrow. The STS deliverable will be an examination of the aviation industry and of the next steps needed to create a sustainable future. The aviation industry is at a critical crossroads. Exploding travel demand and climate change are combining to create a major crisis. There are many challenges when it comes to alleviating the environmental impacts of commercial aviation. Future research will help examine the various regulatory, technological, and cultural challenges to achieving a green future of air travel.

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