The Aviation Industry's Transition to a Sustainable Future:

A Multi-Level Perspective Analysis

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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

Today's world is largely dominated by air travel – we often look to the sky on a clear day and see contrails tracing flight paths across a sea of blue as people move around the globe. Aviation is central to our lives, and we rely on it to get where we would like to go. But as aviation grows, so does its carbon footprint. Tons of greenhouse gasses are released into the atmosphere as fossil fuels are combusted inside incredibly powerful jet engines to keep massive metal aircraft suspended in the sky. With growing concerns about climate change comes motivations to minimize climate impacts wherever possible, and aviation is not exempt from this critical eye. Various flight technologies have evolved in recent years to enable environmentally sustainable flight, and hopefully, these will one day be incorporated into the expansive patchwork of the aviation industry.

In this thesis, I assess the aviation industry as a whole, asking what is the industry doing today to become more environmentally sustainable, and what are different parties' motivations. Official communications from government departments, international councils and associations, and the media have established an international goal of reducing carbon dioxide emissions from aviation to net-zero by 2050. This goal is predicated on developments in sustainable aviation fuels (SAFs), hydrogen propulsion, and various improvements in efficiency reaching sufficient levels by 2050. I argue that the industry at large is making strides toward reducing harmful emissions, but it is not doing enough in the present to ensure that these targets will be met by 2050. Through my research, it appears that the technologies will need more time than that to reach sufficient maturity and to be scaled up for widespread use in the industry. There is a lack of financial incentive to accelerate the production and implementation of sustainable flight technologies, and until it becomes profitable, industry sectors will be reluctant to invest in them.

Background

Motivations for Change

As the effects of climate change have become evident and environmental sustainability has gained attention, the public eye has become more scrutinous of the aviation industry's contributions to climate change. In the year 2000, it was reported that 2-3% of global carbon dioxide emissions came from aviation, and this share has increased since then (Owen et al., 2010). The aviation industry has since devoted growing amounts of resources to the development and implementation of sustainable flight technologies to combat its significant contribution to greenhouse gas (GHG) emissions.

A primary motivation for these developments comes from US government departments, the International Civil Aviation Organization (ICAO), and the International Air Travel Association (IATA), who have set goals of achieving net-zero emissions by 2050. The earliest declaration of this goal I found was in the 2021 US Climate Action Plan report, written by US Transportation Secretary Pete Buttigieg. The goal is proposed on behalf of the US Department of Transportation and the Federal Aviation Administration (FAA). Here, this goal is defined as net-zero lifecycle emissions for carbon dioxide, nitrous oxide, and methane. This goal was set for the US aviation sector as well as any flight involving two ICAO member states. The report calls on aircraft technologies, operational improvements, SAF production, and more, explaining that all of these technologies will be needed to reach this goal. (Buttigieg, 2021). I attempted to dig deeper into the FAA's involvement in this goal and discover the motivations behind it, but I was thwarted by changes made since the beginning of President Trump's term. The FAA sustainability website, as accessed in 2024, cited Buttigieg's report and pointed to increased use of SAF and more efficient aircraft technologies and flight operations as paths to achieving net-zero emissions by 2050. However, I can no longer access this website, as the https://www.faa.gov/sustainability link is no longer viable. (FAA, n.d.). I believe the IATA resolution, which was passed in 2021, will be even more impactful than the Buttigieg report. The IATA includes some 340 airlines, operating in 120 countries. In the passing of their net-zero resolution, all IATA airlines committed to achieving net-zero carbon emissions from their operations by 2050. (IATA, n.d.). Although these organizations differ slightly in their definition of achieving net-zero emissions, the consistent deadline of 2050 has been a strong motivator for sustainable aircraft technology research, airline investment in new sustainable aircraft, as well as widespread research into the feasibility of these goals and actions that must be taken today.

Pressures from the ICAO and FAA could add some urgency to the push for sustainable flight technologies, but their publication of the net-zero by 2050 goal does not come with any financial incentives. So despite encouraging airlines to make sustainability more of a priority, the implementation of new technologies is expensive and does not pose any financial benefit in the immediate future. The IATA commitment to net-zero emissions is similar, as it fails to incentivize rapid changes to focus on environmental sustainability. However, airlines do have quantitative increases in revenue due to IATA membership; being a part of the IATA increases airline reputability and publicity. Therefore, if the IATA enforces the deadline of 2050, then we could possibly see large-scale change across airline prioritization of sustainability since remaining a member of IATA has financial consequences.

Overview of Sustainable Flight Technologies

Two key reports on environmental sustainability in today's aviation industry helped shape my research. First is an excellent 2024 report by Nafisa Lohawala and Zhiqing (Phoebe) Wen, writers for Resources for the Future, about challenges and strategies for greener aviation. Lohawala and Wen (2024) identified four sustainable aviation technologies: SAF, hydrogen aircraft, electric aircraft, and hybrid-electric aircraft. While SAFs can reduce fossil fuels by up to 94% (Prussi et al, 2021), their key challenges are high production costs and lack of sustainability in the scale-up of its production. Hydrogen use can reduce environmental impacts, but green hydrogen is very costly to produce and transport. Electric aircraft can be entirely renewable energy-powered but are limited in passenger capacity and range. Electric vertical takeoff and landing (eVTOL) aircraft are on the rise but face lengthy aircraft-specific FAA certification processes. Also, there is a lack of existing infrastructure for rechargeable aircraft at airports. Similar pros and cons exist for hybrid-electric aircraft, which have slightly better capacity and range but come with increased emissions (Lohawala and Wen, 2024). The other report, published in 2023 by Luke Jensen et al., explores hypothetical routes to achieving net-zero emissions by 2050. Jensen discusses potential improvements to fleet operations and SAFs in depth. Jensen argues that standard improvements in technologies and operations (mostly phasing out old aircraft for newer, more efficient ones) expected by 2050 would only be able to decrease emissions by 30%. The remaining 70% is only achievable if the industry leans heavily into the scale-up of SAFs. If we want to be reliant on SAFs to achieve net-zero emissions by 2050 in aviation, we'd have to increase SAF production by 57% annually until 2030 and then by 13% per year following 2030.

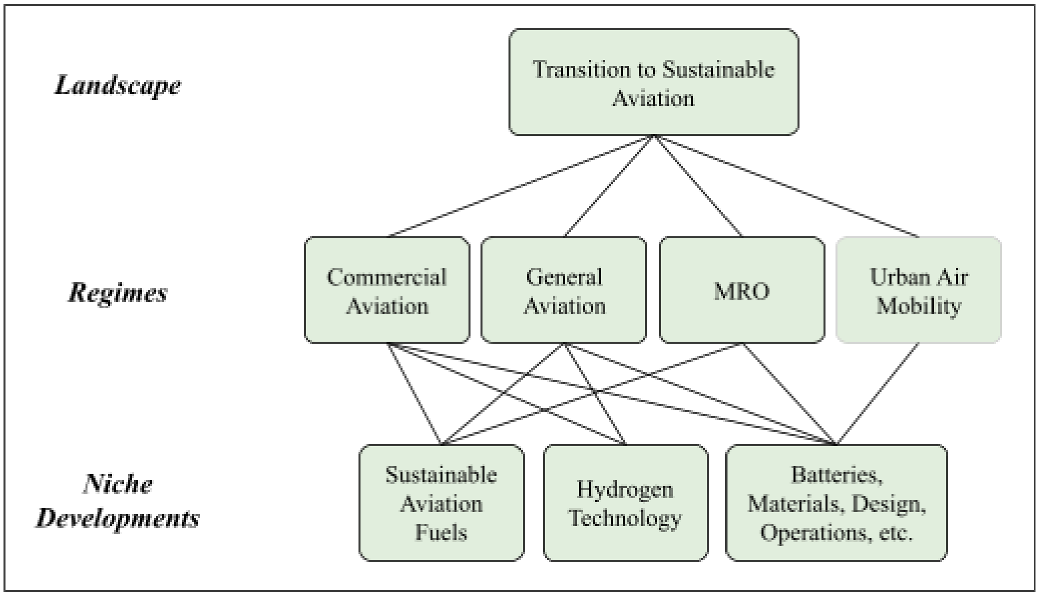
These reports both provide a good sense of the latest technological developments, but in my research, I connected these technologies with existing institutions in the industry to give a clearer picture of sustainability across the entire sociotechnical landscape of aviation.

Research Methods

For this research, I employed the multi-level perspective (MLP) framework, as it is a useful tool for assessing macro-scale transitions through the study of niche technologies (micro-scale) and associate institutions or regimes in place (meso-scale). The sociotechnical landscape is the scale on which technological trends or transitions take place, which is deeply structured, defined by a broad set of economic, political, or technological factors, and it is hard to change; regimes are the next level down, where changes transpire faster than landscapes, but regimes are long-standing structures that constitute the landscape and draw on niche technologies; and lastly there are niche technologies, which are insulated from regime norms enough for them to develop as their own radical technologies. (Geels, 2002). Aviation as a whole is too large to analyze in this thesis, so I used this framework to create a meaningful analysis focusing on only a handful of technologies and regimes.

Furthermore, MLP is particularly useful in the analysis of sustainability transitions. Sustainability-related sociotechnical transition differs fundamentally from other technological innovations. Rather than being justified with economic potential alone, sustainable innovations are fueled by widespread societal interest, as environmental sustainability affects us all and we therefore all have an explicit interest in it. This incorporates a broad range of perspectives and thus creates a need for a framework to capture and organize these perspectives. MLP is able to do exactly this (Geels, 2011, Smith et al., 2010).

Combining my prior knowledge of aviation with what I learned from Lohawala and Wen and Jensen et al., I created a diagram of my multi-level perspective analysis:



MLP Diagram Created for this Thesis, Adam Snyder

I chose the following regimes or constituents of the industry: commercial aviation pertains to passenger flights and airlines; general aviation includes non-airliner aircraft such as personal and business aircraft; maintenance, repair, and overhaul (MRO) encompasses aircraft upkeep and support operations; urban air mobility is a new, emerging field which is being enabled by new electric and hydrogen aircraft and has not become established as mainstream yet, but it can be defined as short-distance air travel in and around urban areas that is publicly available. I would also consider military aviation to be a significant regime in this landscape, but I omitted this because environmental sustainability is not a significant motivator in the development of defense aircraft and for the sake of my own time limitations in this research.

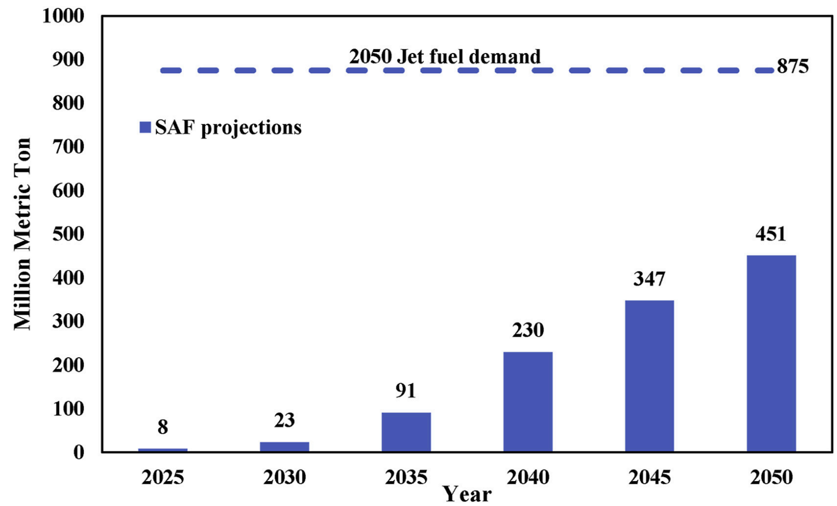
I conducted my research mostly by reading published journal articles and reports accessible through Google Scholar. According to my diagram above, I researched each technology and regime somewhat independently to find contemporary sources on each topic. I then synthesized the information from this research and drew my own conclusions to create this thesis paper.

Findings and Discussion

Niche Technologies

Sustainable Aviation Fuels, or SAFs, are perhaps the most immediately useful of all sustainable aviation technologies. SAFs are alternative aviation fuels that are produced from non-petroleum feedstocks and can be used as drop-in fuels, meaning existing aircraft can blend in a percentage of SAF with their standard fuel and fly as usual. SAF feedstocks include sources such as solid waste, organic biomass, fats, and more. Different SAFs have different life-cycle GHG emissions and different blending limitations depending on their feedstock and chemical pathways (US DOE, n.d.). In a calculation of life-cycle GHG emissions for aviation fuels, researchers found that SAFs can reduce GHG emissions by up to 94% compared to traditional fossil-based jet fuels (Prussi et al., 2021). Despite this, SAF use can only decrease aircraft emissions by small amounts, currently, because of restrictions on how much SAF can be blended into aircraft fuel. Across the seven types of SAFs approved for use in turbine engines, allowable drop-in amounts range from 10% to 50%. It has been demonstrated that 100% SAF turbine engines are safe and effective, though, through flight tests performed in 2021 by Rolls Royce and Airbus. To comply with the 50% blend limitation, they flew an aircraft with one engine using 100% conventional jet fuel and the other one using 100% SAF (Undavalli et al., 2023). These tests indicate that SAFs could be readily used in commercial flights if they were not limited by scale-up difficulties and regulations.

Sustainable aviation fuels are limited in impact, as current SAF production quantities are far lower than the market demand for jet fuel. Synthesizing data published by the IATA and ICAO, Vamsikrishna Undavalli et al. (2023) created the following chart showing the expected rates of SAF production in the coming decades:



Courtesy of Undavalli et al., 2023

As illustrated, the expected quantity of SAF produced in 2050 will be about half of what is needed to sustain the aviation industry. Similarly, authors Jensen et al. (2023) explain in their report that SAF production would have to increase by 57% annually until 2030 and then 13% per year following 2030 – overall multiplying 2022 levels of production 425-fold by the year 2050. A scale-up of this size is extremely challenging and unlikely to be achieved.

SAFs face scrutinous regulatory approval processes, further stifling their ability to reduce GHG emissions from aviation. All jet fuels must achieve ASTM certification in order to be used in flight. In a study of the certification process for alternative aviation fuels, the ASTM certification process was found to be long and rigorous. There are over a dozen measured properties that must be within specific quantitative ranges, such as thermal coefficient of expansion, specific heat, flammability limits versus altitude, minimum spark ignition energy, and more (Wilson et al., 2013). Even after meeting all of these criteria, fuels must then go through a multiphase testing and qualification process before gaining ASTM certification (ASTM, n.d.). Such extensive testing and qualification procedures require both time and money, further decreasing the likelihood that SAFs will be used as primary fuel sources in mainstream flights anytime soon.

Hydrogen power is another key development for sustainable aviation, as hydrogen can produce power without releasing harmful greenhouse gases as byproducts. There are two different uses of hydrogen within aircraft propulsion: first, liquid hydrogen (LH2) can be burned with oxygen, like fossil fuels can, producing strong thrust and emitting only water molecules as a byproduct; hydrogen fuel cells harness electric potential to create power, and can be stacked to function as batteries fueled by the flow of hydrogen and oxygen (Adler and Martins, 2023). Used in aviation, hydrogen combustion can reduce climate impact by 50-75%, and hydrogen fuel cell propulsion could by 75-95% (FCH-JU, 2020). In his 1991 textbook on Hydrogen Aircraft Technology, G. Daniel Brewer explains that LH2-powered aircraft have improved safety, performance, and operating costs compared to traditional fossil-fueled aircraft. Hydrogen has the highest gravimetric heat of any fuel (most energy per weight), meaning that an LH2-powered airliner would only require about ⅓ the weight of fuel that a jet-fueled airliner carries.
The main challenge in designing hydrogen aircraft comes from its extremely low density and fuel storage challenges. In order to carry the required amount of LH2, aircraft would require about 4 times the volume of fuel tanks as compared to jet-fueled aircraft. (Brewer, 1991). Beyond this design challenge, LH2-powered aircraft face challenges due to a lack of research and additional time barriers created by certification procedures. Liquid hydrogen fuel would require cryogenic storage tanks for safe storage, which haven't received the attention and testing

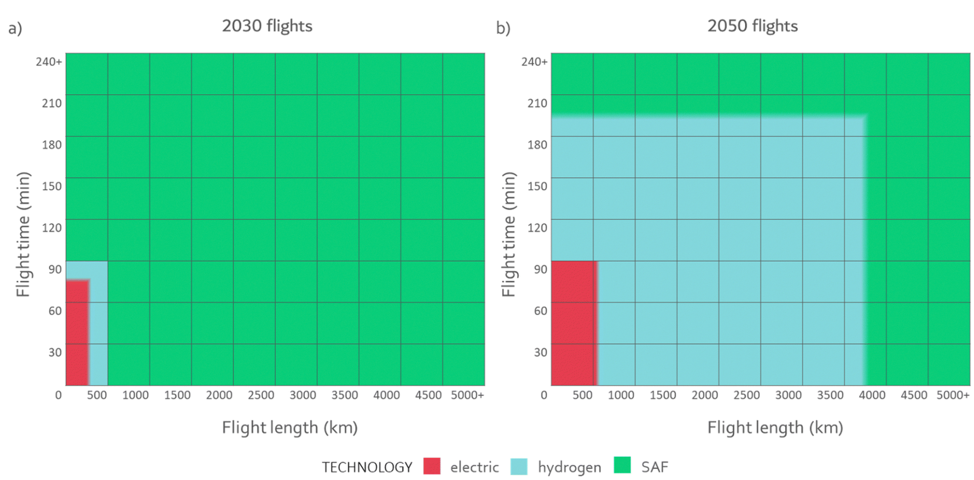
necessary to be operational in the near future (Tiwari et al., 2024). The hours of research and the quality of materials needed to elevate hydrogen combustion to industry standards are very costly. This research will need more financial incentivization to become worthwhile, and it isn't being prioritized enough right now to reach market readiness in the near future.

Hydrogen fuel cells could also be impactful, as these are heavily researched and already being implemented. These mature technologies have enabled electric aircraft startups such as Joby Aviation and ZeroAvia to develop powerful, all-electric aircraft. I would not expect hydrogen fuel cells to make a significant impact on aviation's GHG emissions, as they are limited to the emerging Urban Air Mobility (UAM) sector. Larger sectors within the industry, such as commercial aviation, have power requirements that cannot yet be satisfied by electric propulsion and therefore rely on combustion engines. The limits of the hydrogen fuel cell's flight ranges and duration eliminate a lot of current flight routes and pose minimal opportunity for increased revenue. Perhaps as UAM becomes more popular, hydrogen fuel cells could take over a large portion of flights that might otherwise be fueled by fossil fuels.

Beyond SAF and hydrogen, many other technological developments have furthered the transition toward an environmentally sustainable aviation industry. To name a few: the advancements of lithium-ion and other batteries allow for higher specific energies and greater power storage, enabling the development of electric aircraft that could replace aircraft servicing shorter flight routes; new materials developing allow for lighter and more aerodynamically efficient airframes and skins, which reduce drag and allow for less fuel consumption and therefore GHG emission; modern engineering tools and methodology have allowed engineers to design more efficient wing configurations which create similar benefits; continued research into flight operations allow for reduced waste in commercial aviation. While each of these technologies is impactful, I did not conduct in-depth research on them, as their novelty, impact, and presence in academia are limited in comparison to SAF and hydrogen advancements.

Industry Regimes

The largest and most critical sector within the industry is commercial aviation. This sector includes thousands of airliners flying countless flights every day all over the globe, so I wouldn't expect any rapid changes to decarbonize this industry. There are several manufacturers and airlines making strides in adopting new technologies to reduce GHG emissions. Airbus, for example, launched the ZEROe project in 2020, researching multiple hydrogen-powered aircraft. In 2025, their focus shifted toward hydrogen fuel cells, and they are currently developing a ZEROe turboprop regional aircraft. Delta, American Airlines, and British Airways have invested in zero-emission regional jet developer ZeroAvia as they continue to develop their hydrogen-electric turboprop. Many sustainable startups, like ZeroAvia, have taken off in recent years as electric, hybrid-electric, and hydrogen-powered aircraft prove to be feasible for a small flight envelope (a set of flight ranges and durations). This is illustrated in a publication by Steve Griffiths et al. (2024) as shown below:



Courtesy of Griffiths et al., 2024

As illustrated on the left, hybrid and electric technology in their current states can only cover a small portion of all commercial flight envelopes. SAF is much more robust and widely applicable, but its production is currently nowhere near where it must be to decarbonize the industry. In order to expand the red and blue envelopes, as shown on the right for the year 2050, research and development must be heavily focused on maturing hydrogen and electric aircraft technology, while at the same time, our fuel and energy industries must scale up SAF production.

Beyond simply advancing or expanding these rising technologies, contemporary literature suggests adapting airline operations and supply chains or introducing incentives to further promote sustainable flight. Griffiths et al. (2024) propose that we establish green flight paths (GFPs). Their idea is to establish a network of airports with reliable suppliers of SAF, such that airlines hoping to reduce their carbon footprint would focus flight routes on these airports. Airports would be incentivized to establish green supply chains, as being part of a GFP would promote more traffic and a better public image for the airport. This was inspired by green corridors in the shipping industry, which have proven useful in promoting reduced emissions (Griffiths et al., 2024). This idea was reinforced in interviews conducted by researchers Batoul Modarress Fathi et al., who studied the European commercial aviation supply chain. They established through interviews that the only way to reach emissions reduction targets is to focus efforts on both the aviation supply chain and emerging sustainable flight technologies (Modarress Fathi et al., 2023). No singular change or new technology will be sufficient to achieve net-zero emissions in the near future, so it is essential that we take a multi-faceted approach to decarbonizing commercial aviation. As mentioned previously, commercial aviation lacks the necessary incentives to move toward this multi-faceted approach. Implementing GFPs or sustainable supply chain targets could provide these incentives.

General aviation (GA) is much different from commercial aviation, as it involves smaller and simpler aircraft and affects a much smaller portion of our population. Within GA and pilot training practices, stakeholders are highly concerned with sustainability and are trying to make this sector less harmful to the environment. Because of its smaller profile, GA remains under the radar in public discourse and politics, but it still contributes to aviation GHG emissions as well as noise pollution (Stiebe, 2023). Research has shown that electric propulsion could be a viable alternative for many GA aircraft, as they have smaller flight envelopes, lower weights, and less power required than airliners. A study by Yang Wang and Rongxin Feng established several battery types, including hydrogen fuel cells and lithium-ion batteries, along with various electric motor configurations that would fit weight and power requirements for GA flights (Wang and Feng, 2020). Although feasible, GA pilots and instructors don't view current electric aircraft as viable alternatives for GA flights and pilot training. Interviews show that these stakeholders are interested in promoting environmentally friendly general aviation, but electric aircraft pose several challenges that make them impractical for use. Allowable weights are too low, long charging times prove challenging, and their endurance is too short to complete full flights as defined within Private Pilot's License (PPL) training (Stiebe, 2022). Interestingly, these stakeholder opinions conflict with research published by Wang and Feng, perhaps indicating that Michael Steibe's interviewees are unaware of current technological capabilities or that Wang and Feng failed to consider PPL flight requirements. Beyond technological shortcomings, trends toward GA sustainability are stifled by bureaucracy, politics, regulation, and high costs (Stiebe, 2022). Slow-moving electric flight approval processes challenge flight instructors and make it nearly impossible to practice in electric aircraft when training for one's Private Pilot's License. Additionally, small airports lack the infrastructure to operate electric vehicles at a reasonable cost. The GA sector has a relatively small impact on total GHG emissions from aviation, but it remains a priority for pilots to increase sustainability measures in GA when they become feasible and affordable.

Serving as a backbone for commercial and general aviation, the Maintenance, Repair, and Overhaul (MRO) industry encompasses all activities related to keeping aircraft safe, airworthy, and operational. While we may not often see this type of work, it is a large sector of the aviation industry and is estimated to contribute 5-10% of each aircraft's lifetime GHG emissions (Chester, 2008).

This industry is globally dominated by just over a dozen companies, and I have found through literature that many of these companies do not consider GHG reductions to be a top priority. In a lengthy report on transformative trends across aerospace MRO, author Max Menk details changes in industry organization, motivations, and customer reliability, but only dedicates a portion of a page to a discussion of environmental sustainability (Menk, 2024). It is clear that sustainability is not a high priority within MRO. Similar to commercial aviation, MRO companies do not stand to benefit from increasing sustainability measures, and they are unlikely to without some sort of policy change or financial stipulation. Similarly, in an exploratory study of worldwide MRO practice, researchers found that only 4 of the top 13 global MRO companies publish reports on environmental impact or sustainability (Swastonato and Johnson, 2024). Unfortunately, it appears that MRO as a whole has other goals which take priority over sustainability considerations. Among companies that do prioritize this, however, there has been significant progress over the past couple of decades. I accessed sustainability reports from two top MRO companies, HAECO Group and ST Engineering, and found that they have been making changes to reach company-wide sustainability targets. ST Engineering reduces GHG emissions through operational optimization, increased use of photovoltaic cells for energy production, and increased use of virtual meetings to reduce air travel (ST Engineering, 2021). They do not foresee any radical technological changes making vast impacts, so they have focused on chipping away at GHG emissions wherever possible. HAECO Group has also incorporated increasing amounts of photovoltaic cells for energy production, and they aim to replace 10-15% of their current fuel consumption with SAFs (HAECO Group, 2021).

Lastly, Urban Air Mobility (UAM) – sometimes referred to as Advanced Air Mobility – is emerging as a new regime within aviation. Inspired by the once-futuristic dream of flying cars, UAM is a vision for the future of urban transport and aims to popularize short-range taxi rides through the air. This field will be dominated by eVTOL aircraft which resemble a mix of helicopters and fixed-wing aircraft and are powered by electric propulsion systems. In the US, Joby Aviation and Archer Aviation – eVTOL startups out of Northern California – have been trailblazers in the formation of this new industry. Since July 2022, these companies have worked closely with the FAA to establish rules and regulations as well as airworthiness criteria for UAM companies (FAA, n.d.). eVTOLs are becoming more popular in the media as their technologies mature. By the end of 2024, Archer had partnered with United and Southwest Airlines and Joby had partnered with Delta (Goldstein, 2024). While UAM is yet to be widely integrated into our aviation industry, this field shows promise and is a focal point for airliners over the next couple of decades.

Electric vehicles are optimal for the UAM sector. Air taxi routes span metropolitan areas and aim to carry only a handful of passengers. Limited duration, range, and payload requirements point to electricity as an ideal power source. Furthermore, electric propulsion systems are quieter than combustion engines and will be the preferred option for flying at low altitudes over populated areas. As this field continues to develop, more resources will be poured into electric aircraft and carbon emissions will be replaced by green energy consumption.

Synthesis of Technologies and Regimes

Commercial and general aviation are responsible for the large majority of carbon emissions from all civil aviation in the US, and I have found that they are both incorporating niche developments for environmentally sustainable flight. In the short term, airliners such as Boeing and Airbus can make meaningful contributions to decarbonization by putting pressure on the ASTM to allow for increased SAF use in passenger aircraft and by partnering with fuel producers to accelerate the scale-up of SAF production. SAFs are a quick and effective solution to the carbon emissions problem, as they can be blended with traditional aviation fuel and dropped into the engines of existing airliners. They do not require engine modifications, new aircraft designs, or adapted flight operations. It would also be essential for the industry to take action now in funding research into hydrogen aircraft technologies, such as cryogenic LH2 storage tanks and hydrogen fuel cells. Hydrogen aircraft could outperform our existing aircraft if LH2 could be safely handled and stored in fuel tanks, and hydrogen fuel cells have high potential for energy production on electric aircraft. Lastly, commercial and general aviation have had consistent improvements in flight efficiency, as modern technology allows for highly accurate fluid and structural simulations, and new materials can enhance aerodynamics and reduce weight. There are several paths that must be taken to minimize carbon emissions from these sectors. Unless priorities shift soon, however, it is unlikely that net-zero emissions can be achieved by 2050. And I believe that these priorities will not shift toward sustainability until doing so becomes directly profitable for airlines.

MRO is smaller in scale but remains foundational to our aviation industry. While MRO only accounts for a small percentage of aviation emissions, it will be necessary for this sector to offset its emissions if the industry hopes to become entirely net-zero. Through a combination of SAF use and optimization of MRO operations, this goal certainly seems within reach. Again, this will depend largely on the ability of SAF producers to scale up rapidly in coming years.

UAM is interesting as a regime in this MLP analysis because it is entirely dependent on emerging technologies, unlike the other regimes I've discussed. Rather than simply adopting sustainable flight technologies into a non-sustainable field, UAM is entirely based on the future functionality of electric aviation. It may take a portion of passenger flights or perhaps reduce automobile transportation by a small percentage, but either way, it serves as a means of promoting environmentally sustainable mobility.

Conclusion

Given the research I have presented on SAFs, hydrogen-powered aircraft, and other modern technologies, there is no shortage of ways that regimes within the aviation industry can reduce their carbon footprints. SAFs can be readily used to improve environmental sustainability within commercial aviation, general aviation, and MRO, but their impact is suppressed by ASTM regulations for fuel drop-in blending limitations as well as limited SAF production quantities. Hydrogen is a promising alternative to fossil fuels, as it is extremely energy-dense and has no carbon emissions, but it cannot be safely used in practice until supporting technology and infrastructure reach sufficient maturity. Electric and hybrid-electric propulsion are also effective means of reducing carbon emissions, but they can only serve a very limited flight envelope at current levels of power output. A consistent challenge that each of these technologies encounters is that they will not provide more revenue than existing measures, and it is expensive to research and develop these technologies. I call upon governing bodies such as the FAA and US DoT to provide financial incentives to push the industry toward accelerating the implementation of these technologies.

Future sociotechnical research on this topic can expand upon this MLP analysis to be more comprehensive with regard to the aviation industry. Military aviation is a large regime, and it could benefit from incorporating some of these new technologies. There are also more technologies, as mentioned previously, which are promoting sustainability in aviation but I was not able to research in depth. I think a more expansive MLP analysis would be highly beneficial, as it demonstrates to authorities and regimes in place the importance of their support for developing technologies. Further analysis should also be directed to the policy and finances of this industry to better understand what can be done to encourage the industry to shift their focus toward sustainable flight technologies.

Many challenges stand between the current state of aviation and a future with zero emissions, and thus I do not foresee goals of net-zero emissions by 2050 being met. However, many innovations show promise and simply need more time and resources to develop. It is essential that the regimes in place favor new sustainable flight technologies in the coming years to ensure that the future of aviation is environmentally sustainable.

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