The Feasibility of Electric Aviation for Commercial Air Transport

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Abstract

This paper will discuss the developments in electric aviation and its infeasibility in serving commercial and international travel. Over the past few decades, aviation has become one of the world's fastest-growing transportation industries, responsible for a significant percentage of worldwide greenhouse gas emissions. Following the recent years of COVID-19 restrictions, aviation will see record-breaking demand as tourists and businesses seek overseas travel via jet aircraft, despite aircraft manufacturers like Boeing and Airbus having reached a plateau in traditional jet engine efficiency. Environmental concerns regarding aviation have prompted an exploration into environmentally sustainable electric powertrains. However, this paper will argue that the present technological and infrastructural capabilities of aircraft manufacturers undermine the feasibility of electric aircraft. It will outline the problems facing electric infrastructure today and suggest short-term alternatives to address environmental concerns facing aviation. Drawing upon the works of aerospace and electrical researchers, including Adu-Gyamfi & Good (2022), Trainelli et al. (2021), and Schäfer et al. (2019), this paper argues how current battery technology, airframe designs, and ground electric infrastructure cannot support commercial, long-range electric flight unless significant efforts occur to advance the aerospace and electricity industry.

Keywords: batteries, electric aviation, feasibility, infrastructure, weight

The Feasibility of Electric Aviation for Commercial Air Transport

Introduction

The aviation sector has become a crucial mode of transportation throughout the past century. With a growing economic dependence on international travel and trade coupled with an increasing global desire to travel following the COVID-19 restrictions, the aviation sector prevails as the world's fastest-growing transportation industry (Adu-Gyamfi & Good, 2022). However, increasing air travel presents the issue of increased airborne emissions, prompting researchers and institutions to explore battery technology to electrify aircraft and reduce aviation's carbon footprint. Despite the ongoing research to implement this new technology, several challenges exist that prevent the actualization of electric aviation. In an analytical research paper, transportation and aeronautical researchers Schafer et al. (2019) remarked that battery technologies require significantly higher energy densities to become economically and environmentally feasible. Gnadt et al. (2019), aeronautics and astronautics researchers from the Massachusetts Institute of Technology, also conjured a four-fold increase in energy densities of current state-of-the-art lithium-ion technology required to enable 500 nautical-mile flights–the minimum threshold for most international routes. Finally, infrastructural capacity for electric aircraft does not exist, and research to implement such illuminates the concern of worldwide power-grid incapacity (Guo et al., 2022; Trainelli et al., 2021). Given the environmental detriments of the growing transportation industry and the present electric solution, to what extent is electric aviation commercially viable as an air transport method? Despite the ongoing research to accommodate this transition, its efficacy is inhibited by current battery technology that cannot support most international air routes and the uncertain future timelines for implementing electric aircraft infrastructure.

Battery Limitations

The battery densities of current lithium-ion battery technology are behind the capabilities required for most international air routes since battery weight diminishes aircraft efficiency and range. Unlike traditional turbojet aircraft that expel fuel leading to weight reductions during flight, the theoretical electric aircraft retains the same dead weight of the battery throughout its operation. In their research paper, Gnadt et al. (2019) evaluated the hypothetical performance of a 180-passenger electric aircraft with the configuration of the Airbus A320neo. The researchers utilized TASOPTe (Transport Aircraft System OPTimization – electric), a design optimization program developed by MIT (Massachusetts Institute of Technology) aeronautics researchers to analyze the airframe, propulsor, and operation performance of the A320neo[1] electric variant. By evaluating aircraft design ranges from 200-1600 nautical miles using 400-2000 Wh/kg[2] batteries, Gnadt et al. (2019) concluded that all-electric aircraft are "likely infeasible with current battery technology" (p. 26). They noted that increasing current battery densities from 200 Wh/kg to 800 Wh/kg could make 500 nautical-mile flights viable, a feat required to enable most international flights (non-ocean), albeit far from reality. In fact, very few electric aircraft today are production-ready, including the Pipistrel Alpha Electro: a small trainer aircraft with a range of only 81 nautical miles (Gnadt et al., 2019, p. 4-5) which translates into a mere hour of flight time. Comparatively, Thapa et al. (2021), in their scholarly article, discussed how weight concerns of current batteries mandate electric "aircraft fuselage [...] to be made in composite material" (p. 177), a costly developmental process that can take decades to implement as most passenger aircraft today comprise cost-efficient metal structures. When evaluating the economic and environmental prospects of various fuel types, Barke et al. (2022), a team of sustainable

[1] A320neo: the modern iteration of the Airbus A320 series; a mid-range, popular passenger get
[2] Wh/kg (Watt-hour per kilogram): a measure of battery energy density

aviation researchers from Technische Universität Braunschweig, argued that sustainable aviation fuels comprising synthetic manufacturing techniques would have better short-term performance due to the existing hurdles with composite material readiness (p. 468). Thus, weight ultimately remains a critical refrain preventing electric aviation from meeting current performance standards of air travel.

With the current energy-density limitations of lithium-ion battery technology, electric aviation simply cannot be feasible. In attempting to remedy battery capacity limitations, researchers also revealed that experimental battery chemistries are unsafe and do not last, such as the highly energy-dense Lithium-Sulfur (Li-S) technology. Adu-Gyamfi & Good (2022), scientific researchers from The Arctic University of Norway, noted that, when put into practice, Li-S batteries only last 180-300 charge cycles and expand considerably during usage (p. 6). The result is an experimental, short-lasting battery that shifts relative to its surroundings during discharge, which is both impractical and unsafe. Likewise, a life-cycle approach to evaluate the CO_2 impact of electric aviation, conducted by Melo et al. (2022), sustainable automotive researchers from Technische Universität Braunschweig, further revealed that Li-S technology, though less environmentally detrimental, “achieves its end of life (EoL)” before the traditional battery technologies (p. 372). Although Barke et al. (2022), in a life-cycle sustainability assessment, discovered that battery-powered aircraft are associated with the lowest economic, socioeconomic, and environmental impact, they based their examination on the problematic Li-S architecture without considering new airframe composite design iterations. If they implemented these necessary design changes, it would skew the impact metrics negatively due to additional material and development requirements. Therefore, other fuel sources must exist that can replicate the envisioned benefits of batteries. Barke et al. (2022) further researched synthetic kerosene derived from polymer electrolyte membrane electrolysis (PEM) to produce the hydrogen required for fuel (p. 466). If fully renewable energy drives the electrolysis, synthetic kerosene theoretically "offers reduction potentials of 95% concerning [climate impact] and 24% regarding [fossil research depletion]" (p. 467). Despite its higher costs, synthetic kerosene can be implemented in existing aircraft, offering environmental benefits while eliminating current batteries' safety and longevity concerns.

Despite the challenges in electrifying aircraft today, other possible use cases of electric technology could reduce airborne emissions, such as hybrid powertrains. The theoretical hybrid system comprises traditional fuel-based combustion technology, which drives an electric generator, powering an electric motor elsewhere. Gesell et al. (2019), mechanical and aerospace researchers from the German Aerospace Center (DLR), utilized GTlab, a propulsion simulation tool developed by the DLR, to analyze the efficiencies of various hybrid configurations. The aircraft in question was the ATR 72, a regional turboprop aircraft, where they determined that a hybrid-electric parallel design[3] could match a pure-electric aircraft's efficiency and allow a 21.6% fuel saving by utilizing only the motor during takeoff (Gesell et al., 2019, p. 1607-1608). Although this phase requires a battery, it need not be massive, increasing efficiency. Also, the hybrid design can serve as a developmentary intermediate prefacing pure-electric technology, allowing for progressive, rather than immediate, enhancements to airframe, material, and battery compositions. Hybrid designs may even benefit from synthetic kerosene to further reduce environmental detriments, building upon sustainability research from Barke et al. (2022). Additional support from Bigoni et al. (2018), aerospace science and technology researchers from Politecnico di Milano, brought a hybrid-exclusive methodology for a local airport to charge small, general aviation aircraft. They discovered that "a hybrid-electric aircraft in this category

[3] hybrid-electric parallel: the gas turbine powers the motor directly; both power the same shaft

appears to be cost-effective with respect to a conventional one" (p. 8) and that any "higher power charge, leads to an extra 320 k€ expenditure in 20 years" (p. 8). Undoubtedly, the benefits of hybridization overshadow those of large, pure-battery-powered commercial jets, especially since airports would likely face special fares for high energy consumption due to battery charging.

Scarce Implementation

The significant international policies required to support electric aircraft in tandem with scarce infrastructural developments add to its commercial infeasibility. New proposals in aviation have historically taken decades to implement (Schafer et al., 2019, p. 161), inevitably affecting timelines such as those proposed by the NASA N+3 and Flightpath 2050 initiatives–two renowned environmental goals to reduce airborne CO_2 and NO_x emissions (Adu-Gyamfi & Good, 2022, p. 1). Larsson et al. (2019), environmental and sustainable technology researchers from various institutions such as the Chalmers University of Technology, outlined the outstanding international climate policies needed to reduce aviation emissions. They proposed taxation on jet fuel, an effective method to promote greener power sources. However, Larsson et al. (2019) noted how governing bodies within countries only "allows taxation for flights between two countries if this is agreed upon in their bilateral Aviation Service Agreement" (p. 792), which requires a specific agreement between any two countries and is therefore slow to implement (p. 792). Adu-Gyamfi & Good (2022) also explained how new aircraft concepts, including electrification, take about "ten years to get certified, which is the second most significant challenge for the electric aviation market after batteries" (p. 8). Since aircraft rely on trustworthy 60-year-old tube/wing designs (Adu-Gyamfi & Good, 2022, p. 8), electrification certification likely cannot meet the 2050 goals above, further distancing its realization. Schäfer et al. (2019), air transport and aeronautics researchers from University

College London and MIT, further emphasized how battery densities of “800 Wh kg^{-1} [(minimum for international travel)] could potentially be reached at around mid-century” (p. 1610). Without timely initiation, electric aviation remains speculative. There is little incentive for its development if environmental goals remain unfulfilled.

More importantly, airports require comprehensive charging infrastructure to support commercial long-haul flights. Electric flight boils down to the local power grid and its capabilities, most of which globally cannot support the immense energy demands of electric aviation. Trainelli et al. (2021), Ph.D. researchers from the Department of Aerospace Science and Technology, Politecnico di Milano, discovered that the 3.5-7 MWh[4] of energy required for the medium-range Boeing 737 aircraft “would translate into an unacceptably long recharging time, incompatible with the usual turnaround time of a liner” (p. 2) and could amount “to 20% of the overall electric energy cost” (p. 2) in Italy, where they conducted their study. Guo et al. (2022), Ph.D. researchers in electrical engineering at Brunel University, outlined the consequences of such sudden energy demands, which could cause “frequency deviation of [local] power system[s]” (p. 8149) and, therefore, energy losses and inconsistencies for civilian users. Although it is possible to build additional generator stations, Guo et al. (2022), in their “study on Gatwick airport indicates that even if only 10% [of] domestic flights are electrified, then £50 million will need to be spent on charging infrastructure” (p. 8150). Battery charging methods are underdeveloped and require significant enhancements to make electric aviation efficient and infrastructurally compatible with the remainder of citizens who depend on reliable electrical power.

Consequently, electric aviation development is a costly investment requiring extensive aircraft design and ground infrastructure changes. Schäfer et al. (2019) affirmed that, under 2019

[4] MWh (megawatt hour): battery capacity. A 1 MWh battery can output 1 million watts for 1 hour

market conditions, the price/performance of electricity falls behind that of fuel and increases in cost over longer distances (p. 163) unless a 50% reduction in electricity price occurs (p. 164). Even so, the dead weight of the battery means that as it depletes, it will have to work harder to support the same aircraft weight, ultimately increasing energy usage and costs. Such weight concerns also necessitate the development of lightweight, albeit expensive composite materials that are rare in nature and may harm the environment in other ways; for example, the extraction and processing of such materials. Additionally, airport charging infrastructure must undergo significant research and development to reduce the risk of power-grid overloading and "large volumes of low-carbon electricity to meet new loads of [electric aircraft]" (Guo et al., 2022, p. 8150). Although small, grid-compatible trainer aircraft such as the Pipistrel Alpha Electro exist, their sub-100 nautical-mile range makes it unattractive when most electric cars surpass that capability at a lower price. Ultimately, the costs associated with realizing the commercial application of electric aviation are too high to justify the benefits, especially with today's limited technologies.

Conclusion

Electric aviation cannot serve commercial air transport due to the extensive performance requirements for long-range flights, and developments in the industry are speculative and require significant, expensive infrastructural changes. Indeed, one of the primary motivators for electric aviation stems from the growing environmental degradation caused by airborne aircraft emissions. Although there are many promising efforts to increase the performance of aircraft battery technology, they have safety and cost implications. Adjusting for underdeveloped electric aircraft infrastructure today would even "lead typically to higher lifecycle CO_2 emission levels compared to jet engine aircraft" (Schafer et al. 2019, p. 164). Aerospace corporations such as

Airbus and Boeing should therefore research alternative energy sources such as synthetic kerosene and hybrid technology while battery manufacturers focus on improving the energy density, sustainability, and longevity of their products. Such will allow time for electrical infrastructure to develop, reducing the potential impact on average citizens who depend on the reliability of electrical power. As technology is a rapidly growing sector, the credibility of this paper may diffuse over time, but it remains an informative source on the current state of electric aviation. Reducing airborne emissions will continue to play a crucial role in meeting long-overdue global environmental goals.

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Evidence of Process

Introduction Development

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Research Paper Introduction

The Commercial Viability of Electric Aviation as an Air Transport Method

The aviation sector has become a crucial mode of transportation throughout the past century. As the economy continues to depend on international travel and trade, coupled with an increasing desire to travel overseas following the COVID-19 restrictions, the aviation sector remains the world's fastest-growing transportation industry for the foreseeable future (Adu-Gyamfi et al., 2022). However, an increase in international travel introduces the issue of increased airborne emissions, prompting researchers and institutions to explore using battery technology to electrify aircraft and eliminate greenhouse gas emissions worldwide. Despite the ongoing research to implement this new technology, several challenges exist that prevent the realization of electric aviation. In an analytical research paper, Schafer et al. (2019), transportation and aeronautical researchers, note that battery technologies require significantly higher energy densities to become economically and environmentally viable in comparison to jet aircraft. Moreover, Gnadt et al. (2019), aeronautics and astronautics researchers from the Massachusetts Institute of Technology, implore a 4-fold increase in energy densities of current state-of-the-art lithium-ion technology required to enable 500 nautical-mile flights–the minimum threshold for most international routes. Finally, infrastructural accommodations for electric aircraft do not exist, and research to implement such illuminates the concern of worldwide power-grid incapacity (Guo et al. (2022); Trainelli et al. (2021). Given the environmental detriments of the growing transportation industry, and the shortcomings of the electric solution, to what extent is electric aviation commercially viable as an air transport method? Despite the ongoing research to accommodate this transition, its efficacy is undermined as current battery technology cannot support most international air routes and future timelines for implementing electric aircraft infrastructure are uncertain.

End of Introduction Draft

Introduction

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End of Introduction Final

MBP #1 Development

~~**Battery Technology**~~

The Commercial Viability of Electric Aviation as an Air Transport Method (Battery Technology, first paragraph)

The battery densities of state-of-the-art lithium-ion technology are behind the capabilities required for most international air routes, as battery weight diminishes efficiency and aircraft range. Unlike traditional turbojet aircraft that expel emissions leading to weight reductions during flight, the theoretical electric aircraft retains the same dead weight of the battery throughout its operation. ~~Additionally, current batteries carry energy densities 48 times less than aviation fuel of the same mass (Adu-Gyamfi, 2022), further affirming its commercial inefficacy. Much research has been done on the shortcomings of existing battery technology, including its dead weight, safety and longevity, and suitability of other power mixes, including hybrid systems involving both electric and fuel propulsion methods.~~

~~It is evident that the limiting factor in an electric aircraft's long-range ability is its battery weight.~~ Gnadt et al. (2022), in their research paper,~~"Technical and Environmental Assessment of All-Electric 180-Passenger Commercial Aircraft,"~~ evaluated the theoretical performance of a 180-passenger electric aircraft with the configuration of the Airbus A320neo~~–a standard narrow-body passenger aircraft.~~. The researchers utilized ~~TASOPTe (Transport Aircraft System OPTimization – electric),~~ TASOPTe (Transport Aircraft System OPTimization – electric), a design optimization program developed by MIT aeronautics researchers to analyze the airframe, propulsor, and operation performance of the A320neo electric variant. By evaluating aircraft design ranges from 200-1600 nautical miles using 400-2000 Wh/kg[1] batteries, Gnadt et al. (2022) concluded that all-electric aircraft is "~~are~~ likely infeasible with current battery technology" (~~Gnadt et al. (2022),~~ p.26). They noted that ~~an increase of~~increasing current battery densities from 200 Wh/kg to 800 Wh/kg could make~~ flights of~~ 500 nautical-~~-~~miles~~s~~ flights feasible, a feat ~~far from reality.~~required to enable most international flights and one far from reality. Moreover, Thapa et al. (2021), ~~and~~ in their report paper,~~"All Electric Aircraft: A Reality on its Way,"~~ discussed the several stages required to realize the commercial application of

End of MBP #1 Draft

Battery Limitations

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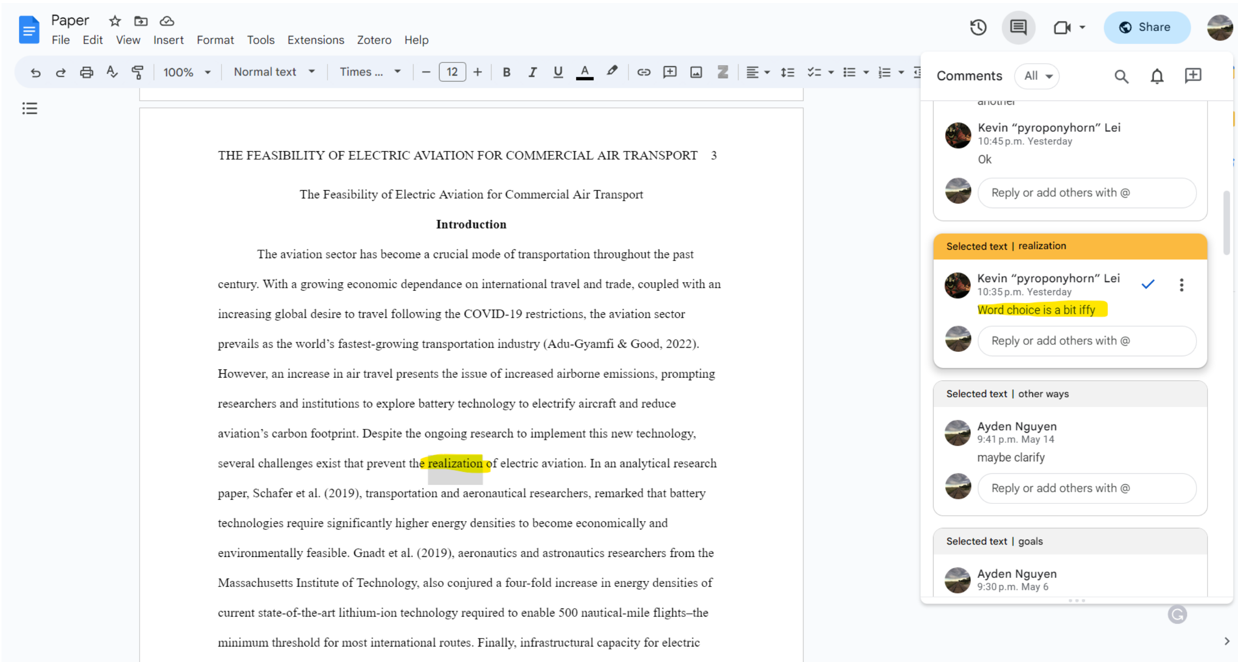
Peer Editing



THE FEASIBILITY OF ELECTRIC AVIATION FOR COMMERCIAL AIR TRANSPORT 3

The Feasibility of Electric Aviation for Commercial Air Transport

Introduction

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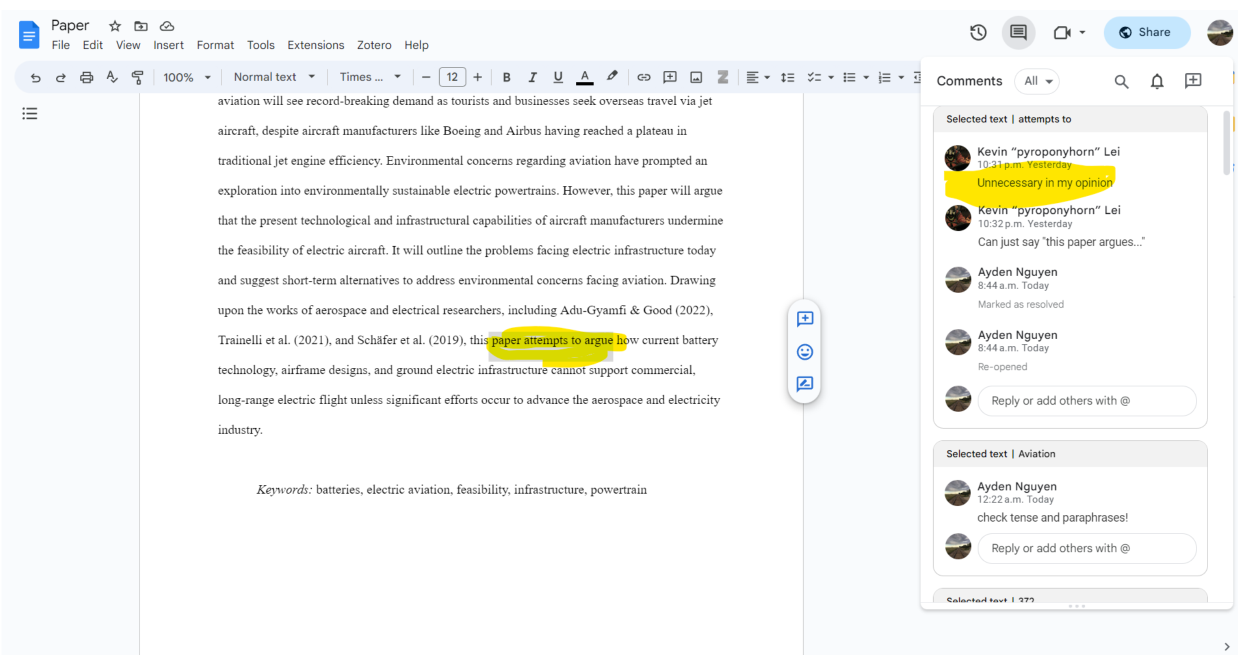

aviation will see record-breaking demand as tourists and businesses seek overseas travel via jet aircraft, despite aircraft manufacturers like Boeing and Airbus having reached a plateau in traditional jet engine efficiency. Environmental concerns regarding aviation have prompted an exploration into environmentally sustainable electric powertrains. However, this paper will argue that the present technological and infrastructural capabilities of aircraft manufacturers undermine the feasibility of electric aircraft. It will outline the problems facing electric infrastructure today and suggest short-term alternatives to address environmental concerns facing aviation. Drawing upon the works of aerospace and electrical researchers, including Adu-Gyamfi & Good (2022), Trainelli et al. (2021), and Schäfer et al. (2019), this paper attempts to argue how current battery technology, airframe designs, and ground electric infrastructure cannot support commercial, long-range electric flight unless significant efforts occur to advance the aerospace and electricity industry.

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