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Research Article

INDUCTIVE ANALYSIS OF FUTURE ELECTRIC AIRCRAFT OPERATIONS – CHALLENGES AND BENEFITS

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Abstract

This research focused on risk and benefit analysis when operating electric aircraft, particularly as it relates to 21st century innovation and aviation needs. The electrification of aircraft can lead to a significant fulfillment of transportation gaps required from future global society. It can also help solve environmental concerns, useful in the context of the transportation world trying to find solutions to ease greenhouse gasses, carbon dioxide emissions, and other harmful pollutants that impact the environment. By using qualitative research methodology, certain questions were explored and answered in the realm of the future usage of electric aircraft. The research approaches include benefits, drawbacks, technological innovations, and certification and regulations concerns. All signs point to this up-and-coming phenomenon being the next natural step for the world of aviation.

Keywords: Electronic aircraft, Aircraft batteries, Aviation risk, Emission reduction, Carbon dioxide.

INTRODUCTION

Electricity has seen and continues to see various uses within aircraft, even going so far as to serve as the primary source of propulsion for various experimental and entry-level airframes (University of Houston, 2021). Electricity has the potential to transform and usher in a new golden age for the aviation industry. Therefore, the aim of this research paper is to seek out and explore how electric aircraft can be further optimized in order to better serve the growing demand of the transportation services required in a 21st-century environment and to solve environmental concerns. With aircraft such as the Boeing 787 and the Airbus A350 using more electric power in various portions of their systems than their counterparts, along with some aircraft being entirely electric-powered, the appeal of exploring additional benefits from electric optimization found itself as the source of emerging interest in recent years (Hamilton and Ma, 2020). Even more critically, the outlying impacts of the benefits of electric power have ramifications that may not be immediately quantifiable, making it necessary to investigate how those benefits can be measured and put to good use. With the optimization and efficiency of electric power sources for aircraft, various positives are recognizable from the outset. For instance, the aviation industry has the potential to save money over the long run, promote a cleaner environment by cutting the output of harmful emissions, and pave forward a green energy revolution in the form of new standards and innovations for others to follow (Hartzell Propeller, 2020). One event that sparked interest in this type of research involves a decision made by United Airlines in 2021. The company recently announced that they will be adding electric aircraft into its fleet and plan to start operating that type of aircraft by 2026 (United Airlines, 2021; Sider, 2021). The aircraft in question is the ES-19 and was developed by Heart Aerospace with the intention to electrify regional air travel. Many electric vehicle manufacturers, such as Tesla, have successfully developed practical and economical cars with electric power.

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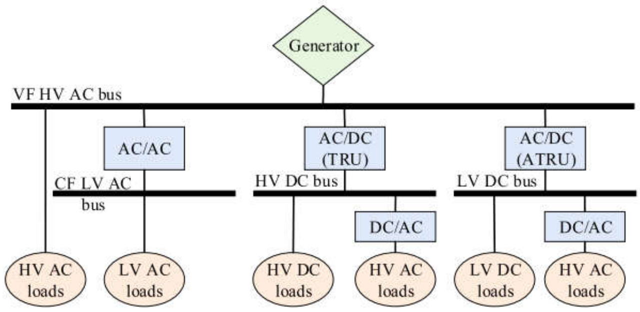
The resulting electric optimization not only improved the reliability but also substantially reduced the operating costs of electric vehicles, especially in comparison with the operation of gasoline vehicles (Sivak and Schoettle, 2018). It is estimated that electric aircraft have a 40 to 230% greater take-off weight compared to conventionally powered aircraft (Rohacs and Rohacs, 2020). The safety and reliability of the systems on an all-electric aircraft should be of utmost importance. Stressors such as vibration and mechanical shock on power electronic components are rated as secondary. Average temperature, temperature cycle, and humidity are more essential stressors (Schefer *et al.,* 2020). There will be further discussion of the optimizations and investigations that will need to take place on these aircraft with enormous electrical powers. Infrastructure is essential when it comes to optimizing that type of airframe. More specifically, electric aircraft cannot be built and maintained without the infrastructure needed to do so. Examples of this include hangars, factories, tools and equipment for assembly, and components for electric power conversion. As of the date of this study, the only flights that have been completed using fully electric systems have been on single-engine prop aircraft.

LITERATURE REVIEW

How Electric Aircraft Operate

Electrification has emerged as a clear answer for the aviation sector, which is searching for a cleaner environmental impact, easier and faster maintenance, increased safety, and cost savings. However, transitioning old hydraulic, pneumatic, and mechanical systems to electrical components necessitates the use of cutting-edge technology. Furthermore, transitioning from fossil fuels to electricity-powered aircraft requires major structural changes, increased electrical power, and improved power generation. As of today, numerous electrical power system schemes have been designed for multiple types of aircraft with different masses to reach economic and environmental targets. In recent years, aircraft manufacturers have started to produce More Electric Aircraft (MEA), transitioning away from previously mentioned traditional pneumatic, hydraulic, and mechanical systems into all electrical systems. For example, the Airbus A380 and Boeing 787 are today's largest civil aircraft that incorporate MEA technologies. One of the main innovations of Airbus in the A380 was the removal of the constant speed drive between the engine variable speed shaft and the generators. By doing so, volume and weight savings were achieved and the reliability of the aircraft was improved (Dorn-Gomba *et al.,* 2020). The next step from MEA would be All-Electric Aircraft (AEA), a venture in which systems in the aircraft, as well as the thrust components, will be replaced with electric systems. Progress in a variety of areas is required to make this notion a reality. Because batteries may be used as an energy source in the future, high overall efficiency is required. As a result, further study into better aerodynamics is a necessity for success. Novel fuselage and wing materials must also be investigated for weight reduction, an important consideration in this venture. High-efficiency electrical drives and high-power density energy sources are required for electrical systems (Schefer *et al.,* 2020). Research being done today varies from conceptual projects to prototypes tested in-flight and in commercial products.



Note: (Dorn-Gomba, Ramoul, Reimers, and Emadi, 2020)

Figure 1. All-Electric Architecture Example

As seen above (Figure 1), electric aircraft are solely powered by an energy storage system (batteries). The architecture is straightforward, with only two direct currents (DC) buses and DC/AC (alternating current) and DC/DC converters used to transmit power throughout the network. Due to a reduced part count in the propulsion electrical path, all-electric aircraft offer a larger potential for propulsion efficiency improvements than turboelectric and hybrid-electric systems (Dorn-Gomba *et al.,* 2020). A power range between 500 kilowatts (kW) and 3 megawatts (MW) is needed, depending on the size of the aircraft. Several concepts and studies have been already reviewed with batteries being the dominant choice of most energy sources. The estimated technological limit for the pure use of batteries in an aircraft is a gravimetric energy density of 500 watt hours per kilogram (Wh/kg). Many scientists are working on increasing this number, meaning that an improved energy density will allow for lighter batteries and extended range. Lithium-air batteries could also be a key technology as they promise high theoretic energy densities (year 2030+: practical densities of 500 Wh/kg ≤). With these approaches, environmentally friendly and cost-effective batteries can be built (Schefer *et al.,* 2020). One final consideration involves important electrical components of the power system: power converters, wires, and safety switches. All of these components must have the highest possible power densities available. The traditional AC distribution system must be replaced with a DC system with a higher voltage level due to the rising energy demand of these. Among the major challenges, designing power electronic converters, and especially inverters, at a power rating of several megawatts raises tremendous challenges that will be further discussed. Electrical propulsion for large commercial applications is on the roadmap, but no airplane has been tested in flight yet. Hybrid-electric and turboelectric architectures are currently being investigated since several megawatts are required (Dorn-Gomba *et al.,* 2020).

Benefits of Electric Aircraft

Aspects from Air Service Providers: Airlines around the world have been looking for a new type of aircraft, such as electric aircraft, which they could operate at a lower cost, as the airline industry has a notoriously low-profit margin. For years, the large investment with a tremendous amount of upfront cost at the developing phase of electric aircraft hindered airlines and aircraft manufacturers from starting their R and D process. In July 2021, United Airlines announced its investment and partnership with Swedish startup electric aircraft manufacturer, Heart Aerospace, for the development of an all-electric aircraft, ES-19, which is set to enter commercial service by 2026. (United Airlines, 2021). Despite the huge amount of R&D costs, the high efficiency and the lower cost (compared with fossil fuel energy) of electric power make it obvious that electric aircraft are the solution to future air transportation, and more airline companies will be following the trend sooner or later. Schäfer *et al.* (2018) explained that the maintenance costs of an electric aircraft would be much lower than a fuel aircraft as it is relatively mechanical-simple and it does not require complex systems or modules such as the auxiliary power unit (APU) and the fuel system (Schäfer *et al.,* 2018).

Passenger Aspect*:* With the transformation of traveling type and global prevailing crises, such as the COVID-19 pandemic, on-demand mobility (ODM), such as air taxis, has become more popular when people are traveling, and electric aircraft could play an important role in future air transportation. Thin-haul commuters and intra-city air taxis are the two applications of ODM transportation. According to Rajendran and Srinivas (2020), air taxi refers to the transportation of on-demand passengers with metropolitan cities, with an average capacity of four; and thin-haul operation refers to the flights that serve cities with small travel demand between the two destinations, often served between remote areas or minor cities (Rajendran and Srinivas, 2020).

Hwang and Ning (2018) find that, with optimization, the efficiency of converting electrical energy to mechanical energy in an optimized electric propulsion system could be as much as 95%, which is a lot better than a traditional turbine engine's 20-30%. The improved efficiency and the removal of the use of fossil fuel energy leads to overall lower operating costs, consequently, airlines would find it becomes practical and profitable to operate these "thin haul" routes, and thus travelers who have demand in traveling between these two locations will benefit from the services provided by the airlines, using the lower costing electric aircraft. Another benefit would be the increased accessibility to regular, scheduled air transportation for people in remote areas, which is currently subsidized by the government through the Essential Air Services (EAS) program (U.S. Department of Transportation [D.O.T.], 2017).

Environmental Benefits: With technological improvements, electric aircraft will become one of the key factors in a vision of a green, sustainable transportation system, which scientists, experts, and government authorities have been pursuing. The possible environmental benefits of electric aircraft include decreased noise and air pollution, reduced heat emission, zero-consumption of fossil fuel energy, and zero-emission of greenhouse gas. More details about the environmental benefits that electric aircraft could bring will be further discussed in the following section. Global aviation accounts for 1.9% of greenhouse gas emissions, 2.5% of carbon dioxide emissions, and 3.5% of effective radiation forcing, a measure of the overall impact on global warming (Ritchie, 2020). Those percentages stem from the processes by which aviation operates; most aircraft are powered by jet gasoline which is converted to carbon dioxide when burned. The feasibility of electric aircraft usage to cut back on harmful emissions poses meritable consideration. If all aircraft were to be converted to electric-use only, there would be a complete elimination of direct combustion emissions and thus a removal of carbon dioxide-related warming, whether it be direct or indirect (Schäfer *et al.,* 2018). The burden that electric aircraft take on with respect to the environment is far more generous than traditional jet fuel-powered airframes. An intensive study has shown that through the observation of metrics from years prior to 2021 if all aircraft in the world were electric-powered in the year 2015 and served flights of up to a distance between 400 to 600 miles, they would demand an equivalent of roughly 0.6-1.7% of worldwide electric consumption (Schäfer *et al.,* 2018). To illustrate the disparity in environmental impacts between traditional and electric aircraft, consider an analysis of a first-generation 180-seat, 150-passenger all-electric aircraft over a range of 400 miles. This aircraft is projected to consume 180 watt-hours (Wh) per revenue passenger kilometers (RPK) over the course of the flight and would generate about 91 grams of carbon dioxide per RPK in the process (Schäfer *et al.,* 2018).

Case Study: ES-19

In July 2021, United Airlines, Inc. announced its investment and partnership with a Swedish startup, Heart Aerospace, which is known for developing all-electric aircraft. The partnership includes a direct investment from United to Heart Aerospace with the expected return being the 19-seater ES-19. Airlines such as United are considering adding all-electric aircraft into their fleets in the near future because of the economic potential possible within the characteristics of the ES-19 such as its relatively small capacity, which makes thin-haul operations practical and feasible (Rajendran and Srinivas, 2020). Further economic benefits of the ES-19 include reduced fossil fuel consumption, lower operating costs, fewer emissions, lower noise levels, etc. According to International Civil Aviation Organization (ICAO) (2017), the aviation industry is growing at a rate of 6% annually and contributes about 2% of global carbon dioxide ($CO2$) emissions (ICAO, 2017). The industry is aiming to reach a goal of carbon-neutral growth starting in 2020 and to reach 50% fewer carbon emissions by 2050 based on 2005 carbon emission levels. By implementing electric aircraft such as the ES-19, the industry could be greatly enriched with additional tools and options to assist in the attainment of these goals in the future. Baumeister, Leung and Ryley (2020) studied the carbon emissions of the ES-19 on specific routes in Finland compared with the emission level of the ATR-72, which will possibly be replaced by the ES-19. The study showed that carbon emission reduction of specific routes can be as high as 64% if those routes are operated by the ES-19 rather than the ATR-72. Once the technological improvements are realized and more renewable sources of electricity are found, the carbon emissions of electric aircraft could drop substantially, and it would be more economical and feasible to operate electric aircraft such as the ES-19 in the commercial aviation or air transport industry (Baumeister *et al.,* 2020).

Infrastructure

The adoption of all-electric aircraft calls for a remodel of many aspects regarding infrastructure including areas such as maintenance facilities and airports. The existing aviation framework is not designed for these types of aircraft. Radical innovation is required, however, due to the fact that the implementation of electric technologies and designs is far behind schedule and fully depends on the wishes of air carriers as to whether it is worth it to invest in costly equipment or not (Das *et al.,* 2016). The cost-effectiveness of new elements to the industry such as batteries, chargers, and electricity as a whole is bound to the success of the implementation of these new technologies or lack thereof. As of today, the only companies working towards the development of electric aircraft are all startups. Ampaire, Heart Aerospace, and Eviation were all started by entrepreneurs who believe that there will be a demand for electric aircraft in the near future. One of the reasons why there is a lack of infrastructure regarding electric aircraft is their power demand. A need for an increased electric power supply has to be accounted for in the reconfiguration of existing airports. Battery recharging stations and battery swapping stations are conceptually similar to today's refueling stations but the problem lies in the time it takes to charge a battery compared to fueling an aircraft (Riboldi *et al.,* 2019). Not only the battery capacity, but if a majority of electric aircraft today were to be implemented, it would require a 26% increase in the world's electric energy production, necessitating capital investments in the order of half a trillion dollars or more. When comparing the price of jet fuel to electrical consumption, electricity and jet fuel cost about the same per unit of energy delivered to a propulsor, although fuel price has historically been more volatile (Epstein and O'Flarity, 2019).

Airworthiness Process and Certification

The retooling of traditional aircraft systems into electric-based ones comes with changes in maintenance procedures and approaches. As an overview from a paper sponsored by the Georgia Institute of Technology pointed out, there has been little discussion about future maintenance issues that pertain strictly to electrically powered aircraft (Naru and German, 2018). This can cause major problems later down the road as electric aircraft become more mainstream combined with a lack of proper procedures to deal with them if not updated accordingly in addition to maintenance facilities renovation. Like with traditional jet aircraft, such training will come from FAA CFR Part 147 aviation maintenance technician schools along with industry guidance and best practices from professionals in the maintenance field (Goldsby *et al.,* 2002). Although existing FAA licensing and certification standards are able to accommodate electric aircraft, curriculum requirements likely require updates in order to ensure that FAA CFR Part 65, the section that governs mechanics and other airmen aside from aircrew, compensate for differences that arise as a result of these new electric technologies. Being able to accommodate changes on a technical basis and allowing those changes to thrive without being hindered are two different things (Goldsby *et al.,* 2002). The needs of other groups such as regulatory agencies, aviation companies, and the infrastructure involved with maintenance have to be considered as well. Consequently, problematic deficiencies of the current maintenance structure can be altered or eliminated for the good of the aviation industry and its future.

Research Questions

- How can benefits from electric optimization in aircraft result in positives for all parties involved?
- Are there drawbacks to converting various power sources into electric use?
- What are the technological improvements that could possibly help the optimization and efficiency of electric aircraft?
- What are the challenges of developing models/prototypes of electric aircraft for future aviation usage?

Research Methodology

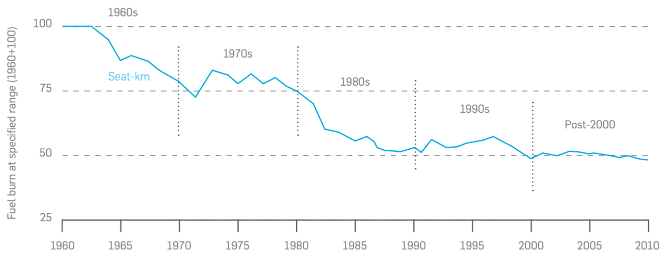
The research in this project focuses primarily on case studies and the exploration of qualitative sources in the pursuit of electric aircraft optimization. This is due to the relative newness of the technology and the lack of significant data from real-world trials. Therefore, this paper focuses on qualitative research methods to analyze existing data and text-based resources. According to Lacey and Luff (2007), the qualitative analysis consists of five stages: transcription, organizing data, familiarization, coding, and themes. Data is deciphered and organized in the first stage and compared with each other for familiarities later on. After that, the data is labeled and organized in the coding process for ease of access and comprehension. Finally, in the theme stage, new concepts and findings will be provided for the conclusion part of the research (Lacey and Luff, 2007). This is pointed out in multiple papers collected over the course of the research as part of the triangulation method in conjunction with a high inter-rater reliability score in line with the aforementioned papers with near-unanimous agreement among them (Carter *et al.,* 2014).

Inductive Findings

In attempts to explore and answer the research questions that guide this paper, we took care to examine the consistency of the information from a multitude of sources, particularly ones in the literature review section. By triangulating those sources in addition to taking on new ones that possess ideal degrees of inter-rate reliability, the authors came to the findings that, among other things, explored the positives involved with electric aircraft, their drawbacks, and external industry considerations such as regulations and policy.

Benefits from Electric Optimization in Aircraft

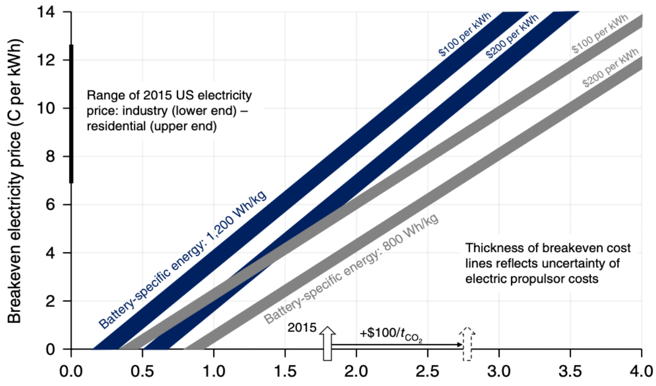
Great improvements have been made over recent years regarding the electrification of commercial aircraft. More electric aircraft (MEA) such as the Boeing 787 and Airbus A350 now use electricity to power pneumatic, hydraulic, and many other systems onboard. However, eyes are now shifting away from the use of onboard electrical systems to electric propulsion, thus the creation of all-electric aircraft (AEA). The electric aviation movement is rapidly gaining pace, particularly as the industry is under increasing pressure to decrease hazardous emissions. Many companies are currently investing in startups and programs to build various sorts of electric aircraft, from retrofit hybrid-electric general aviation aircraft to long-range commercial planes to electric vertical takeoff and landing (eVTOL) urban air taxis, all over the world. However, there are additional strong reasons to advance electric aircraft beyond the obvious environmental benefits. In 2015, the global aircraft fleet consumed 276 million tons of jet fuel, 7% of global oil products. However, reliance on oil products comes at an environmental cost. Aircraft CO2 emissions, owing to the combustion of jet fuel, comprise 2.7% of energy-use-related CO2 emissions (Schäfer, 2018). All-electric aircraft would not only remove direct non-CO2 emissions, but they would also eliminate direct air pollution. While indirect air pollution may occur depending on the power production methods used, ground-based power generation has a larger possibility for emissions management than in-flight combustion. With the introduction of electric battery-powered aircraft, the possibility of charging the batteries with electricity supplied through more sustainable sources – such as nuclear, wind, hydro, solar, and tidal generating arises. However, if non-sustainable ways of power generation are utilized for battery charging, at least potentially dangerous pollutants are emitted away from densely populated regions and the upper atmosphere (Domone, 2018).



Note. Large reductions in fuel burn are seen from 1960 up to the 1990s; however, since then any decrease has been modest, despite the development costs of new aircraft continuing to rise (Domone, 2018).

Figure 2. Average Fuel Burn of Jet Aircraft

Alongside the reduction of harmful emissions, the introduction of electric aircraft allows for cost savings among airlines and passengers as well as reduced audible noise pollution around airports. Cost reductions may also be realized with all-electric aircraft. They would not, for example, require a fuel system or an extra gas turbine (auxiliary power unit) for producing electricity, starting the engine, and so on. Furthermore, due to the relative mechanical simplicity of electric motors, there may be potential for cost savings in engine maintenance (Schäfer, 2018). The economic argument for implementing electric aircraft benefits both airlines and general aviation (Botti, 2020). Figure 3 depicts the potential range of breakeven electricity prices for a first-generation Airbus A320/Boeing 737-sized all-electric aircraft. The batteries in the all-electric aircraft have a specific energy of 800 Wh kg1 (grey lines) or 1,200 Wh/kg (blue lines), with battery prices of US$ 100 kWh or US$ 200 kWh. To attain cost-effectiveness, jet fuel costs would need to be at least US$ 2.3 or 2.8 per gallon, depending on the cost of the battery, based on battery-pack specific energy of 800 Wh/kg. As time goes on and the price of renewable power diminishes and the specific energy of batteries increases then the cost-effectiveness of AEA will improve greatly (Schäfer, 2018).



Note. Jet Fuel Price Per Gallon. (Schäfer, 2018)

Figure 3. Break-even electricity price for a first-generation all-electric aircraft

Another benefit, as mentioned previously, is reductions in noise pollution. Noise, which is generally characterized as unwanted sound, is known to have a number of negative consequences on humans. Noise pollution is still seen as a significant public health issue in the early twenty-first century. Noise disturbance, in particular, is a major source of environmental complaints in cities, with serious consequences for health (Ozkurt, Feyyaz, and Sari, 2015).

Drawbacks and Concerns

On a conceptual level, it is simpler to interface with vital components like electric chargers, infrastructure, and other systems since they already exist for traditional aircraft and mostly only require modifications or adjustments to accommodate new additions to their base frameworks over time. Batteries, on the other hand, are the greatest unknown and have to be built from the ground up as the basis of a line of relatively new technology. Even mundane steps like aircraft design have to revolve around batteries instead of embracing a more traditional streamlined process found not only in fuel-based jets, but plenty of other mediums as well. It is arguably the linchpin of most drawbacks when it comes to electric aircraft in general and continuously emerges as a sticking point in most findings on the topic. Weight remains a considerable factor at the heart of optimization efforts. As it stands, it is difficult to find solutions for the required power-to-weight ratio for the batteries needed to operate electric aircraft. The more capacity a battery has, the more weight is required to store the capacity at a level acceptable for ranged flights. The break-even point of that ratio contributes to why the range of currently-possible electric aircraft is short. Furthermore, there are limitations on the types of electric-friendly batteries available for use. Most of them have issues with energy optimization, shown by the fact that current lithium-ion batteries are roughly a hundred times less energy-dense than gasoline, a fuel type used in traditional aircraft (Rowden and Garcia-Araez, 2020). Therefore, the capacity of those batteries has to increase to make up for that shortcoming, which in turn increases battery weight and necessitates the need to solve an ever-encroaching expansion of storage requirements to accommodate the weight and the increased capacity needed to do so. There are some possible solutions to this problem that involve nanotechnology, increased density in a smaller footprint, usage of air in lithium, and others (Ellingsen *et al.*, 2016). If any or parts of those concepts are incorporated properly, electric aircraft will be put on a reliable path to be optimized to the point where they can be sustainable within the aviation industry. Furthermore, besides fire hazard, a typical electric battery's energy efficiency averages about 200 to 250 watt-hours per kilogram with about 800 watt-hours required to sustain optimization to a degree that makes flying with electric power readily available (Hepperle, 2012). The table below (Figure 4) illustrates what an optimized future can look like as those batteries reach their full potential.

System	theoretical specific energy	expected in 2025
Li-Ion (2012)	390 Wh/kg	250 Wh/kg
Zn-air	1090 Wh/kg	400-500 Wh/kg
Li-S	2570 Wh/kg	500-1250 Wh/kg
$Li-O_2$	3500 Wh/kg	800-1750 Wh/kg

Specific energy density of current and future chemical battery sys

Note. (Hepperle, 2012)

Figure 4. Energy Density Projections

There are certain rules of linearity bundled with built-in exponential growth occurrences to extrapolate when it comes to measuring timescales in which those battery types can meet expected energy densities. The following chart (Figure 5) issues forecasts of what sort of reasonable timing can be expected from such optimization.

Note. Specific energy [Wh / kg] (Hepperle, 2012)

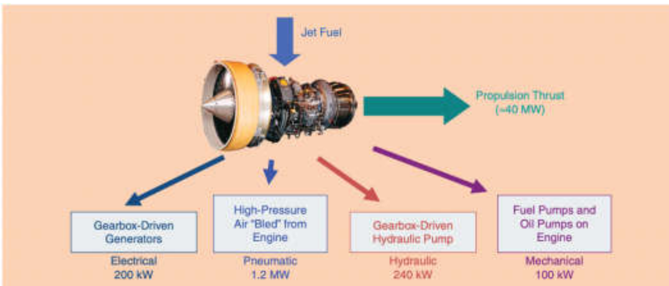
Figure 5. Energy Comparisons and Future Outlook

Although projections from Figure 5 are time stamped at the 2012 mark, they represent realistic predictions of battery refinement timelines and are fairly in line with what is happening in the industry as of the moment of this study. Findings at this point in time suggest that, unlike their traditional counterparts, initial conceptions of electric aircraft will struggle to maintain enough time in the air to make point-to-point services and sustained operations worth pursuing. Capacity is an ongoing problem for the batteries available in the current market since they have to trade storage for weight, signaling why it remains the linchpin for drawbacks. At best, introductory models may be able to muster 20 to 30 minutes of flight time with optimal duration reaching up to as much as 45 minutes in some cases, reserve power notwithstanding (Geiß and Strohmayer, 2021; Rendón *et al.,* 2021). This poses a need to overhaul pricing models or continue to wait until electric aircraft can solicit even more flight time in order to make sure that flights can actually be worth the time and effort it takes to get them in the air in the first place.

Industry Development

Electrification of Traditional Fuel-Consuming Aircraft

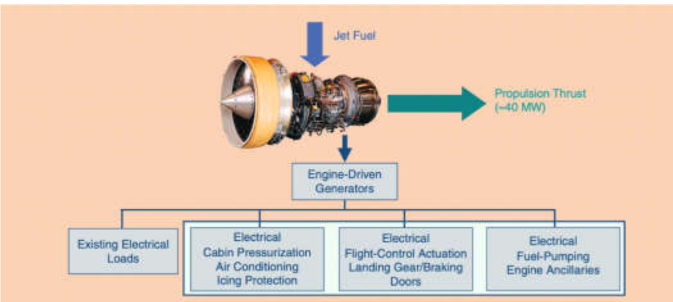
In the beginning state, the "electrified" parts are only limited to small parts in the cockpit, such as the instruments. Moving on to the second and third-generation aircraft, commercial jets were incorporated with electrical systems such as the cockpit primary and secondary flight displays (PFD and SFD), the flight management system (FMS), and the Terrain Warning and Awareness System (TWAS). As time moves on and technological improvements progress, the new concept of "fly-by-wire" or "more electric aircraft" (MEA) increases the use of electrical power on larger modules and systems on an aircraft (Rosero, Ortega, Aldabas, and Romeral, 2007). Traditionally, the turbine engine on the first-generation aircraft, such as the Boeing 707 and DC-8, provided power sources to four main subsystems on the aircraft (Figure 6): the pneumatic system, the hydraulic system, the mechanical system, and the electrical system (Wheeler and Bozhko, 2014).



Note. (Wheeler and Bozhko, 2014)

Figure 6. Power systems on a traditional aircraft

Given the concept of "fly-by-wire", the more electric aircraft built starting from the 2000s (e.g. Airbus A350 and Boeing 787) have a larger electrical system with much larger engine-driven generators that serve as the power sources for the electrical system (Figure 7), along with the pneumatic, hydraulic, and mechanical systems (Wheeler and Bozhko, 2014). The improved efficiency of aircraft performance aircraft electrification improves passengers' comfort is the elimination of the environmental control system (ECS). To improve aircraft efficiency, the Boeing 787 has been achieved by the electrification of cabin air systems that were previously powered by fuel-consuming engines (Sarlioglu and Morri, 2015).



Note. (Wheeler and Bozhko, 2014)

Figure 7. Power systems on an MEA aircraft

The Hope of All-Electric Aircraft

During the last decade, with the rise of environmental awareness and technological improvements, the concept of "all-electric aircraft" has become more realistic and feasible in the world of commercial aviation. The concept of all-electric aircraft is to power all modules and systems, including power plant solely by electricity power, and batteries will serve as the source of the required power on the all-electric aircraft (Schefer *et al.,* 2020). In recent years, pioneering operators and leading manufacturers expect electric aircraft to enter into service five to six years from now. One of the products that seem close to commercial usage is the 19-seater ES-19 by Heart Aerospace, a Swedish startup electric aircraft manufacturer. There are other electric aircraft products that are close to entering into service, including the eVTOL-equipped Airbus' City Airbus and the Eviation's nine-seater "Alice" for the thin-haul routes (Rajendran and Srinivas, 2020).

Challenges of Electric Aircraft and Future Usage

Challenge of Limitations

Due to the high costs of the electrical propulsion system and the generally high fares resulting from the high production costs, electric aircraft operators are expected to suffer financial loss in the early stage. The objective of "lower to zero-emission" of electric aircraft could actually lead to another challenge: whether the process of generating the power required for the electric aircraft contradicts the philosophy of "zero-emission". The power of electricity that supplies the battery should be generated "eco-friendly" and economically, otherwise, the process of power generation will contradict the philosophy of "zero-emission" and fail to fulfill the purpose of developing electric aircraft.

The last challenge faced by the manufacturers and operators of electric aircraft is the safety and reliability issues, and the future policies and regulations derived from these issues (Moir, 1998). In terms of the emission reduction, the operation of ES-19 showed an reduction in carbon emission on some domestic routes in Finland compared to that of ATR-72 (Baumeister, Leung and Ryley, 2020). This means current technology only allows electric aircraft to effectively reduce carbon emission within a specific distance limitation, otherwise, it will enter the stage of "diseconomies of scale" (Stigler, 1958).

Challenge of Regulations

The safety and reliability of electric aircraft are the top concerns before the certifications of aircraft. Referenced to the historic data, the certification processes of a new "clean-sheet" aircraft could take years to complete, with numerous tastings. The concept of "all-electric" aircraft is relatively new to the public and the industry, therefore the required tastings on its safety and reliability could take even longer before, compared with previously certified aircraft, the regulators and government entities, such as the Federal Aviation Administration (FAA), to pass the corresponding regulations and certifications for electric aircraft. In addition to the level of safety, the types of operation allowed to be operated by all-electric aircraft could vary. Based on the level of safety and reliability, each aircraft could be certified for different types of operation. For example, an electric aircraft could be certified for general aviation (GA) operations (14 CFR Part 91) but not qualified for usage for scheduled (14 CFR Part 121) or non-scheduled air transport operations (14 CFR Part 135) (FAA, n.d. a, b, and c).

Conclusion

It is possible for electric aircraft to have a future in the aviation industry and that they have an abundance of potential to utilize when it comes to optimization. The benefits of allowing such innovation to proceed far outweigh any potential drawbacks or detractors to the technology. To that end, electric aircraft are able to be powered by sustainable and clean energy sources, reduce the prices of various industry-related mechanisms such as tickets and fuel for optimal economic benefits, and greatly reduce the level of noise pollution and other harmful environmental impacts on humans and Earth alike. Subsequently, technology limitations, poor energy output potential, limited time in the air, requirements for reserve power supplies, and inefficient power to weight ratios are drawbacks that plague initial conceptions of electric aircraft. However, those issues are solvable and stand ready to be greatly improved in the coming years as the findings make abundantly clear. They are supported by historical observations of the "electrification creep," a term that refers to the slow increase of systems within traditional aircraft that become electrified or electric-only as airframes transition into fully electric powerhouses. And lastly, it is evident that the progress made in electric aircraft optimization must be accompanied by a range of new rules and regulations imposed by the aviation industry and government entities alike to maintain safeguards on innovation due to some deficits in current guidelines.

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