Preparing for the Next Generation of Mostly Electric Aircraft

Electrification adoption rates climb throughout aerospace industry in response to emissions concerns, but challenges still exist

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Introduction

Most industry experts agree that **the future of all transportation is more electric.** Advancements in electric and autonomous vehicles have sparked renewed enthusiasm for the integration of hydrogen power and battery power in aviation. Startups from Silicon Valley and elsewhere are partnering with key players from aerospace and transportation to make electric aircraft more viable, according to aerodefensetech.com. Without a doubt, **clean technology is the biggest trend in aerospace globally,** allowing the world to reduce carbon emissions as we jet across the globe.

The drive behind the electric movement in aviation, not surprisingly, is based on increased concerns about environmental impact. Although kerosene burning aircraft engines are greener today–because they burn less fuel than they used to, there are a lot more aircraft in the skies, so the contribution to air pollution is still significant. And the number of aircraft is only expected to increase as the aerospace industry is growing exponentially. In fact, by 2028 it is predicted that upwards of 38,000 aircraft will be in service, a vast increase from the 26,000 being used today (based on data reported in equipment-news.com).

As a result, aviation emissions have doubled since the mid-1980s, accounting for 2.5% of global carbon dioxide emissions in 2019. That number could triple by 2050, according to greenbiz.com.

Such an alarming statistic is one reason why the global market for electric aircraft is projected to skyrocket, **potentially reaching $27.7 billion by 2030,** according to market research company MarketsandMarkets. Experts say the growth in this market stems largely from urban mobility aircraft deployment (see more on this topic later in the article) and the increasing use of electric aircraft for light cargo and other activities.

Although electrification has become a global trend, the EU is driving the greatest interest in this area with a goal of being **net neutral (not net zero) by 2040.** Europe already is estimated to account for the largest share of the aircraft electrification market in 2022 with particularly high demand from countries such as France, Germany, UK, and Switzerland, according to marketsandmarkets.com. Government bodies such as the European Union Aviation Safety Agency (EASA), the European Defense Agency (EDA), the UK Civil Aviation Authority (CAA), and the European Air Transport Command play a crucial role in ensuring transportation safety and addressing various issues related to air transport, such as carbon emissions and noise pollution, among others.

The elimination of fossil fuel burning engines is made possible by the introduction of electric propulsion motors powered by all electric powered propulsion.

Current technologies have made it possible to electrify small aircraft. But electrifying larger aircraft requires a different approach, since battery power densities do not exist today to make it feasible for large aircraft to be powered solely by batteries. In addition, there are ongoing challenges relative to the weight of batteries, as well as heat management issues with the size of batteries necessary to power larger aircraft.

This whitepaper is designed to **summarize existing technologies that are making electric aircraft more viable,** as well as address some of the **remaining engineering challenges** that preclude the industry from going completely electric.

Where the Industry is Today

While electric flight has been around since the 1970s, it was largely considered experimental. As of February 2020, there are more than 170 electric plane projects trying to achieve certification, which is up 50% since the spring of 2018, according to militaryaerospace.com.

For the foreseeable future, electric planes will be limited in how far they can travel. **Today's best batteries put out far less power by weight than traditional fuels:** an energy density of 250 watt-hours per kilogram versus 12,000 watt-hours per kilogram for jet fuel. The batteries required for a given flight are far heavier than standard fuel and take up more space. **Approximately half of all flights globally are fewer than 800 kilometers,** which is expected to be within the range of battery-powered electric aircraft by 2025, according to scientificamerican.com.

According to Tracy Rice, Group Vice President of Technology and Innovation at Parker, small commuters—19 seaters or less — can today run on solely battery power, while regional, 100-seaters are capable of being powered by fuel cells (gas or liquid). Hybrid propulsion systems, which typically have gas turbines, used in conjunction with hydrogen powered fuel cells or batteries, also are becoming popular in providing electric power during peak demands.

Hybrid electric propulsion includes systems that combine electric motors, battery storage, and other forms of aircraft energy generation to increase efficiency and reduce weight by decoupling thrust and power generation and/or providing focused thrust during key operational periods, allowing certain components to be optimized for cruising speeds. Configurations include dual propulsion aircraft with internal combustion engines augmented by electric motors. The electric motors can be powered by batteries providing energy from sources such as solar photovoltaic cells, hydrogen fuel cells, or a traditional generators.

In addition to electric propulsion, the industry continues to see rapid advancement in the more-electric airplane. The transition of hydraulic and pneumatic systems to electric-based systems has opened the door to an unprecedented number of hybrid designs that are quieter and offer lower operating costs and emissions, as well as new design configurations (such as distributed electric propulsion) and new flight control methods. And at the top of the scale, large transport aircraft are transforming conventional subsystems to more electrical subsystems, along with hybrid electric propulsion.

According to a National Academies of Sciences, Engineering, and Medicine study, however, **large all-electric commercial aircraft might not become viable until mid- to late- century.**

Why Electrify?

As previously noted, there are numerous **benefits to electrifying aircraft,** with environmental impact being the greatest. Aviation is one of the fastest rising sources of carbon emissions from transport.

In addition, **aircraft accounted for an estimated 9% of U.S. transportation energy consumption in 2019.** Though this portion is small, in 2019, the U.S. Energy Information Administration (EIA) projected that air would be the only transportation mode expected to see sustained growth in energy demand, increasing this percentage to 14% by 2050, which represents annual growth of about 1.1%.

A particularly strong area for improvement is in flights in the regional travel market—an area projected to have substantial growth for electric hybrid planes in the near term. Today's short-haul route aircraft are up to 50% less efficient than long-haul flights based on emissions.

But there are other benefits to electrification, as well. These include:

- **Longer life spans.** Electric motors generally last longer than hydrocarbon-fueled engines in current aircraft designs, requiring an overhaul at 20,000 hours versus 2,000, according to scientificamerican.com.
- **Reduced costs.** Projected operational cost savings and lower long-term cost advantages represent a substantial motivation for aircraft operators and producers to electrify aircraft. Ampaire, a California-based developer of high-performance, zero-emissions aircraft, projects its 15-passenger aircraft would decrease fuel costs by 90% and reduce maintenance costs by 50%. Such lower cost structures could provide an opportunity to revitalize service on routes that are not currently economical, according to nrel.gov.
- **Noise reduction.** Ampaire suggests 60% quieter takeoffs and landings are possible, which is especially attractive in high-density population areas. The National Aeronautics and Space Administration (NASA) Regional Air Mobility report cites noise as a factor in local communities' resistance to new airports and expanded

air service. Regional electric aircraft have the potential to reduce the noise because of both the electric motor and steep climb/descent profiles of electric aircraft.

- **Increased accessibility.** In addition to reducing emissions by switching air travel to clean electric power, encouraging a transportation mode shift away from ground transport for regional destinations also could reduce congestion and vehicle parking requirements at airport hubs for those accessing larger markets. For travelers to and from rural areas, electric aviation could provide an economical, clean alternative while reducing travel time and costs.
- **Economic development.** According to a Washington State study, airports and public entities are primarily interested in the potential for electric aviation to spur economic development by serving currently underserved areas or opening markets that have been phased out.

Persistent Challenges for Fully Electric Aircraft

Challenges to the use of electric propulsion in commercial aviation are many and range from the batteries and motors to the wiring and cooling. To make fully electric aircraft a reality and eventually commonplace requires advancements in battery technology and highly efficient electric converters. Fossil fuels currently provide 100 times as much energy as batteries do, according to aerodefensetech.com. Adding more batteries to aircraft increases weight and the risk of chemical and fire hazards. Breakthroughs in energy storage and distribution are needed to address these challenges.

Another way to store energy for electric motors is to use **hydrogen.** Stored in liquid form at a cryogenic temperature of -253C (-423F), hydrogen is lighter than conventional Jet-A1 kerosene for a given amount of energy. The process of converting it to electricity in a fuel cell is well known, although challenges remain. Liquid hydrogen requires larger tanks because of its low density compared with jet fuel. And the scalability of fuel cells to the megawatt levels that commercial aircraft require has yet to be proved, according to aviationweek.com. Safety is also an ongoing concern considering the high volatility of hydrogen.

Beyond the challenges of identifying an efficient power source are other concerns that are deterring the rapid growth of electric aircraft, including **safety concerns.** Heat loads (thermal management) rank toward the top of that list of concerns as the industry continues to work to develop more solutions in temperature control and heat transference. This, in turn, puts more focus on specifying efficient products which have less heat rejection.

In high-altitude aircraft, traditional air-cooling solutions like **fans can get clogged with ice.** When it comes to electronics bound for space, the opportunity for **natural convection or airflow simply doesn't exist,** so thermal engineers must look for new ways to dissipate heat away from critical components. To ensure these components don't overheat, liquid cooling and cold plates have become the more viable solutions currently available. A problem is that many of these active cooling systems are heavy and costly.

Yet another **safety concern revolves around higher voltages.** With greater demand for electrical power comes requirements for higher voltages that greatly exceed those in aircraft currently in production.

Electrified aircraft propulsion also requires higher voltages to minimize the size and weight of the power-distribution system. Watts equal volts times amps so, at high power levels, increasing the voltage lowers the current and reduces the size of the aircraft cabling needed to distribute the power.

Aircraft have traditionally used 28 volts for power distribution, but newer aircraft are beginning to use 270 volts. The first all-electric aircraft are using voltages of up to about 800VDC; however, designers who are looking at megawatt-class electrified-propulsion systems for single-aisle airliners are talking about kilovolts—up to 3,000 volts, according to aviationweek.com.

Such high voltages in the reduced air pressure at cruising altitudes of commercial aircraft could lead to a **potentially hazardous phenomenon known as partial discharge.** So new cabling designs and insulation systems will have to be developed to avoid hazards such as partial and corona discharge.

Still another hurdle is the challenging environment in which aircraft operate. Unlike in other industries, aerospace electronics must survive in some of the world's harshest environments, endure extreme weather conditions and handle regular fluctuations in temperature, airflow and pressure—not to mention how these devices are also subject to things like extreme vibrations, with takeoff and landing putting a heavy mechanical burden on equipment and internal electronics.

As a result of these extreme variables, the process of estimating how temperature changes and heat flow will impact a device's reliability becomes very complex. While these challenges have always existed, new trends and innovations are driving further change in the industry and introducing an array of new considerations for aerospace engineers. Leading manufacturers like Parker continue to innovate to raise the bar on temperature performance so that components can survive in higher temperatures.

Where the Industry is Heading in the Future

The emergence of new technologies is expected to drive market recovery in the wake of the economic setbacks caused by the COVID pandemic and accompanying decreases in air travel. Areas of focus for **original equipment manufacturers** (OEMs) and operators include fuel and power efficiency, maintenance costs reduction, and new mobility patterns.

The move toward electrification of aircraft has benefited the engine segment with significant R&D investments. This trend will continue and expand to other segments, such as motorization, as alternatives are sought to replace hydraulic and pneumatic systems in next-generation aircraft, according to frost.com.

With the development of advanced materials, there is significant growth potential in distribution and storage systems. New technologies are expected to reduce the size and weight of components while increasing their efficiency and autonomy. Additionally, the need to meet the demand for new, lighter, and denser batteries will further boost the aircraft EPS market.

The propulsion systems segment is projected to lead the aircraft electrification market by 2030. Electrification of propulsion systems is expected to boost the power for take-off as well as climb, thereby creating an efficient electrical replacement for a regular turbofan with a 2-megawatt liquid-cooled electric motor. The increasing penetration of electric propulsion is expected to reduce fuel burn substantially, leading to a decrease in atmospheric emissions.

Beyond these general growth areas, **engineering technology trends to watch** in the coming years within the aerospace industry include:

- **The increased use of hydrogen to power aircraft.** Airbus, which has been at the forefront of hydrogen technology in aviation, recently revealed three concepts for the world's first zero-emission hydrogen commercial aircraft, which could enter service by 2035. These concepts each represent a different approach to achieving zero-emission flight by exploring various technology pathways and aerodynamic configurations to support the decarbonization of the entire aviation industry. All the concepts presented by Airbus rely on hydrogen as a primary power source—an option which they believe holds exceptional promise as a clean aviation fuel and is likely to be a solution for aerospace—and many other industries—to meet their climate-neutral targets. Some of the hydrogen on board would be burned in a gas turbine (a less efficient use of hydrogen, however), and the other portion could be converted into electricity in fuel cells. During the flight phases requiring maximum power, such as takeoff and climb, both the turbine and an electric motor would drive the propeller or fan. In cruise flight, the propeller or fan would rely on the turbine only, which would be optimized for that phase. The electric part of the propulsion system would thus make a key contribution to an overall more efficient configuration.
- **Structural health monitoring (SHM).** This involves the observation and analysis of a system over time using

periodically sampled response measurements to monitor changes to the material. The foundation of structural health monitoring is the ability to monitor structures using embedded or attached nondestructive evaluation (NDE) sensors and to utilize the data to assess the state of the structure. During the past decade, researchers have made significant advances in developing NDE sensors for SHM, and they have developed the hardware and software needed for analysis and communication of the SHM results. The NDE SHM sensors that have reached some modest degree of maturing and are able to monitor significantly large areas of structures include fiber optics, active ultrasonics, and passive acoustic emission.

- **Improved battery efficiency.** Some industry studies show that battery efficiency is improving at about 5–8% a year. NASA conservatively projects those batteries with 350-Wh/kg energy density at the pack level could be commercially ready by 2030 and would enable all-electric, short-range, 30-seat aircraft. The organization additionally projects that 400-Wh/kg batteries could be commercially ready by 2035 but believes that exceeding 400 Wh/kg will require investment in new battery technologies. Pack-level energy densities of 400-500 Wh/kg are viewed as a sweet spot that would open up potential applications in hybrid-electric aircraft ranging from 50-seat regionals to 150-seat single-aisles.
- **Superconducting technology.** Besides energy storage, aircraft propulsion needs advances in the power densities and efficiencies of electric motors and power electronics beyond automotive levels. High-power densities will reduce weight and volume, while higher efficiencies will reduce waste heat and the weight of the necessary cooling systems. In a megawatt-class aircraft propulsion system, even losses as low as 1-2% require the removal of kilowatts of waste heat. Airbus is exploring the use of superconducting technology in electrical machines and distribution cables. Superconductors are materials that have no electrical resistance when cooled to cryogenic temperatures, thereby increasing efficiency and reducing weight. According to aviationweek.com, using superconducting motors and cables would increase power density and reduce waste heat, but in most all-electric or hybrid-electric aircraft, that would require the addition of complex, heavy cryocoolers. Hydrogen-powered aircraft, however, could use their cryogenic liquid-hydrogen fuel to supercool the systems.
- **Three-stream jet engines for military applications.** GE and Pratt & Whitney have led efforts in the development of true three-stream jet engines in which the core engine airstream and fan-bypass stream are joined by a third bypass stream that flows around the outside area of the engine case. Benefits of the innovative engine design include better fuel economy, additional thrust and more durability than traditional jet engines.

Evaluating the Impact of Digitalization Trends as Aircraft Get Smarter

As is the case in many other industries, **digitalization** is transforming the aerospace sector. Currently, there is a constant flow of real-time information coming from aircraft updating ground operations and the pilots on the status of systems, equipment and weather conditions. However, this is simply the beginning of what is possible with the integration of digital technology across the sector.

There is an ongoing focus on providing more data and analytics to better monitor the health and performance of the components and help predict failures. Low-cost sensors are in greater demand than ever to monitor a wide array of issues. This includes a need for better oxygen and humidity sensors on inerting systems to reduce the potential for explosions in the fuel tanks.

Across maintenance departments in the industry, **data is being monitored and analyzed by artificial intelligence (AI) and machine learning systems.** In fact, according to equipment-news.com, airlines in Asia already have begun implementing AI tools for simulation and data modeling of aircraft. This information can then be used to decide precisely when an aircraft's components should be replaced or repaired and when other maintenance is required. This integration has helped to ensure that the lifespan and function of individual parts are fully optimized, and the overall aircraft systems are kept safe. By using AI to monitor and predict requirements, it is

possible to ensure that all required maintenance equipment and parts are ready for when the time is right.

In recent years, **Virtual Reality (VR)** alongside big data has pushed the boundaries of predictive maintenance. Since 2016, Airbus has been making use of this technology to help boost Asia's maintenance, repair and overhaul (MRO) sector inside its Hangar of the Future initiative in Singapore.

VR and augmented reality (AR) technologies are disrupting traditional techniques of aerospace maintenance by allowing engineers to see maintenance activities from new and unexplored angles. This means that new data can be captured, and advanced simulations can be created to train maintenance teams for future procedures, as well as allow personnel and pilots to view and test virtual replicas of the aircraft equipment before physically handling them.

One of the downfalls of the rapid uptake in digitalization is the risk of data security and breach of privacy. This uncertainty applies to the aerospace sector especially, where the increasing connectivity of systems also is putting aircraft at risk of hacking and attack from cybercriminals and terrorists.

Despite these concerns, according to the Aerospace Industries Association's Vision for 2050, new innovations are coming online regularly to transform the aerospace and defense industries, which are already among the largest users of such advances as additive manufacturing technology.

AAM Concept Takes Off: Welcome Flying Taxis

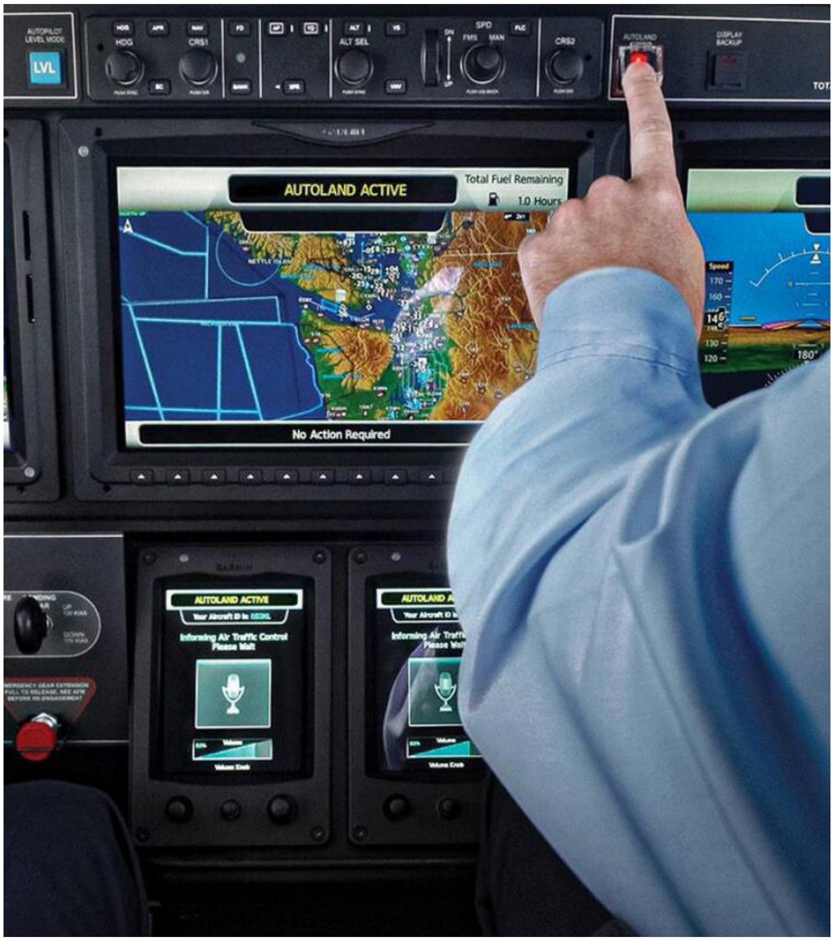
We are entering a new era of aviation. **Advanced Air Mobility (AAM)**—the transformative airborne technology used to transport people and goods in new, community-friendly, and cost-effective aircraft in both rural and urban environments—represents the next gamechanging point in the aerospace industry's ongoing evolution. AAM is expected to be the next significant change in mobility and, perhaps, the global economy, as it could lead to fundamentally new capabilities and applications that were previously not feasible.

AAM technologies promise to transform how people and cargo are moved, driving the United States' economic engine. Deloitte estimates that the American AAM market alone will reach **US $115 billion annually by 2035,** employing more than 280,000 people in high-paying jobs. By 2030, passenger AAM operators (sometimes referred to as flying taxis) could rival today's largest airlines in flights per day and fleet size, according to McKinsey reports.

AAM uses electric vertical takeoff and landing (eVTOL) aircraft that are usually short range, runway independent, and highly automated. They incorporate nontraditional electric or hybrid propulsion for piloted or automated operations. Electric motors and simplified electronic controls can improve upon complex transmissions, flight-critical components, and mechanical reliability while also substantially reducing the manufacturing, operating, and sustainment costs. This aircraft design innovation could enable many new complex missions in urban, suburban, and defense environments, some of which are now conducted by ground vehicles, traditional helicopters, and fixed-winged aircraft.

AAM technology is being developed by the **traditional aerospace, automotive, and technology companies, as well as by numerous startups around the globe.** Deloitte estimated in 2021 that more than 200 companies worldwide are developing eVTOL aircraft, with more than a dozen projects receiving significant private industry investment. As of September 2020, private players had invested more than US $2 billion globally in developing these aircraft; this includes both traditional aerospace companies and new entrants with little or no prior aerospace experience.

Government agencies such as NASA and the Federal Aviation Administration (FAA) have taken leading roles in key research and policy areas. Incremental developments in different fields such as energy storage, electric propulsion, and sensors, which are critical pieces of AAM, are also in the works. As a result of these collaborative and diverse efforts, AAM is poised to be a leading mobility reality in the 2030s.



Conclusion

The increased adoption of electrification technologies in the aerospace industry is creating opportunities to push the limits of current technologies, identify new alternative solutions, increase mobility in dense and underserved communities, and produce cleaner, more sustainable modes of transportation. These same changes, however, come with risks in the areas of safety, reliability and efficiency, along with possible increased costs.

Balancing the risks and rewards of electrification is key to identifying optimal designs and approaches to the next generation of aircraft.

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