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Electric Aircraft Working Group Report

ACKNOWLEDGEMENTS

Department of Commerce

Zunum Aero

The Boeing Company

Volta Enterprises

Verdego Aero

magniX

Diamondstream Partners

Stellar Aerospace

Aerospace Futures Alliance

Andrew Graham Aircraft Consulting

Kenmore Air

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Federal Aviation Administration

Seattle Tacoma International Airport

Wenatchee Pangborn Memorial Airport

Airline Pilots Association

Kitsap Aerospace Defense Alliance

Avista Utilities

Puget Sound Energy

EAWG REPORT EXECUTIVE SUMMARY

The Washington State Department of Transportation Aviation Division, at the direction of the legislature, formed a working group with the goal of exploring the electric aircraft industry and how electric aircraft technology could be used to expand regional air transportation in the state of Washington. This report is required in ESSB 6106, Section 212 (4). Members of the working group represent the electric aircraft industry, the aircraft manufacturing industry, electric utilities, the battery industry, the state Department of Commerce, the Department of Transportation Aviation Division, the airline pilots association, a primary airport representing an airport association, investment firms and the airline industry. The group selected work in areas that affect the industry. Each member provided valuable information towards the introduction of these aircraft into commercial service.

The aircraft development and subsequent manufacturing process is challenging for any new aircraft. Electric and hybrid-electric aircraft manufacturers are innovating both in terms of propulsion and battery technology. This innovation requires the cooperation and collaboration with the Federal Aviation Administration to develop standards and regulations for these systems. Battery technology for use in large aircraft propulsion is in its infancy and is an important factor in bringing larger electric aircraft to market. Currently batteries are heavy and lack the required energy density for larger aircraft. Manufacturers and designers have dealt with this by developing smaller aircraft. Some manufacturers plan to develop the aircraft initially as a hybrid with the potential of converting to fully electric once the battery technology is further developed. Many of the entrants in the electric aircraft market are smaller startup companies who require sizable investments from outside investors.

Washington State has unique geography that makes traveling within the state challenging and often time consuming. Improvements in regional air travel options could greatly expand a citizens' ability to travel easily and efficiently throughout the state and region. Electric and hybrid-electric aircraft are forecast to offer lower operational costs for air carriers. If air carriers are able to operate more efficiently and at a lower cost, the savings may allow them to offer commercial air service to underserved communities. The electric and hybrid-electric aircraft that are currently being developed are anticipated to accommodate 9-15 passengers. Because of the aircraft's smaller size they will be able to operate from runways as short as 3,000 feet in length. Over half of the airports in the state would be able to accommodate the landing distance required for electric and hybrid-electric aircraft. Short takeoff and landing capabilities coupled with lower operational costs make these aircraft viable for the role of increasing intrastate and interstate air travel. Industry and the markets will determine if initial use of these aircraft are on demand, scheduled charter service or for business travel.

Electric and hybrid-electric aircraft promise to reduce consumption of fossil fuels and greenhouse gas emissions. These aircraft are projected to operate at 85% to 90% efficiency, 20% to 40% more efficient than piston and turbine aircraft. Because the energy used for propulsion is electricity, the emissions are tied to the electric grid and the source that is generating that electricity. Washington State benefits from obtaining the majority of its electricity from renewable sources. A concern of electric aircraft is the disposition process for the batteries that are no longer viable for aircraft use. It is possible that these batteries are subsequently re-used in a secondary operation such as backup power for server locations, to reduce the impact on the environment.

Aviation work force is another concern. The aviation industry is currently facing a large shortage of pilots and aircraft maintenance technicians. Demand for air travel is rising, and with the advent of expanded regional air service the shortage will only worsen, in the near term, as industry and aviation education centers work together to meet the needs. Similarly, manufacturers of electric aircraft are working to minimize the amount of required retraining for the pilots and technicians operating and maintaining the aircraft. Manufacturers will also need to engage with aircraft maintenance schools to ensure maintenance technicians have the necessary skills to maintain and manufacture electric aircraft.

Finally, similar to electric vehicles, electric aircraft will require modifications and/or additions to airport infrastructure in order to accommodate aircraft battery charging. Handling peak loads for electricity demands requires planning. Some of the electrical demands could be offset by using solar power on airport property.

Recommendations moving forward:

The Electric Aircraft Working Group finds, that given the potential to expand aerospace manufacturing; open up new markets providing both economic and public benefits; impact the development of the next generation of aircraft resulting in a reduction of greenhouse gas emissions and noise pollution; and provide a regional transportation option that provides relief to congested roadways; continuing to study while working towards the integration of electric propulsion of aircraft is in the best interest of the state.

Resource Recommendation: Resources are required for continued support of Washington's Electric Aircraft Working Group. A qualified aerospace consultant should further the efforts of the working group by examining opportunities for electric propulsion aircraft in Washington State. The study should include the following:

i) Infrastructure requirements necessary to facilitate electric aircraft operations at airports;

ii) Potential economic and public benefits including but not limited to the direct and indirect impact on the number of manufacturing and service jobs and the wages from those jobs in Washington state;

iii) Potential incentives for industry in the manufacturing and operation of electric aircraft for regional air travel;

iv) Educational/workforce requirements for manufacturing and maintaining electric aircraft;

v) Demand and forecast for electric aircraft use to include expected timeline of the aircraft entering the market given FAA certification requirements;

vi) Identification of up to six airports in Washington State that may benefit from a pilot program once an electrically propelled aircraft for commercial use becomes available;

vii) Recommendations to further the advancement of the electrification of aircraft for regional commercial use within the state;

The study and accompanying recommendations should be provided to the transportation committees of the legislature November 15, 2020. The department should also provide a progress report on implementation of the recommendations to the transportation committees by February 2022.

ELECTRIC AND HYBRID-ELECTRIC AIRCRAFT USE IN WASHINGTON STATE

I. Background

In the spring of 2018, Washington State Department of Transportation Aviation Division (WSDOT) was tasked by the legislature with forming a working group to explore the feasibility of introducing electric or hybrid-electric aircraft for regional air transportation in the state. The group was comprised of subject matter experts from a variety of different fields that are likely to be impacted by the introduction of electric aircraft. Members of the working group represent the electric aircraft industry, the aircraft manufacturing industry, electric utilities, the battery industry, the state Department of Commerce, the Department of Transportation aviation division, the airline pilots association, a primary airport representing an airport association, investment firms and the airline industry.

The work group was to consider and make recommendations on the feasibility of electric or hybrid-electric flight given:

- Federal certification requirements
- Current and anticipated advancements in battery technology
- Infrastructure requirements and capacity impacts at primary airports
- Need for and feasibility of industry incentives
- Potential for public private partnerships
- Impacts to revenues generated from aviation fuel sales
- Educational requirements for maintaining electric or hybrid-electric powered aircraft
- Homeland security checkpoint requirements
- Public acceptance of the technology
- Cost comparison of fossil fuel and electric or hybrid-electric aircraft engines
- Emission reduction potential
- Policy changes needed to facilitate electric or hybrid-electric powered aircraft use for regional commercial air travel in Washington state

WSDOT Aviation organized three working group meetings to discuss how this technology will impact Washington State and air travel in general. The working group discussed the topics requested by legislators along with many other factors that relate to electric aviation. The first meeting was held at Zunum Aero's Headquarters in Bothell and focused on the current state of the electric aircraft industry. The group also brainstormed ideas for how the working group should proceed and topics to research further. The second meeting, held at SeaTac International Airport, addressed manufacturing and certification opportunities and challenges. The final in-person meeting was held at the WSDOT Aviation office in Tumwater. The group discussed impacts on the environment, public perception, and the opportunities for the state of Washington.

Following the first meeting, the working group was broken into six functional area breakout groups to discuss specifics of operating, manufacturing, infrastructure requirements, and other impacts on industry, the state, and the region. The members were subject matter experts in each functional area and were gathered to take a closer look at different aspects of their subject of focus. Section IV of this report will explore these topics in detail.

II. History of Electric Hybrid-Electric Aircraft

While electric aircraft are perceived to be futuristic, the first electrically powered flying machine first flew in 1886, seventeen years before the Wright Brothers flight at Kitty Hawk. Gaston Tissandier, chemist and early aviation pioneer, attached a Seimens electric motor and propeller to a dirigible type airship and flew the craft making it the first electric aircraft. In the year that followed, airship designers, Charles Renard and Arthur Krebs, attached larger, more powerful electric motors to another airship. However, even with the more powerful motors, the airship suffered from a lack of performance due to the heavy accumulators used to store the electricity. Roland Berger (2017)

The first-heavier-than air electrically powered aircraft took flight nearly ninety years after the Tissandier electric airship in 1973. Motor-glider designer and manufacture, Heino Brditschka flew a modified version of his HB-3 motor-glider with an electric powerplant. Brditschka's electric motor-glider was powered by four 24-hour charged nickel-cadmium (NiCad) batteries that all together generated 100 volts giving the aircraft roughly eight minutes of powered flight time. The motor was taken from a forklift and modified for use on an aircraft. His first flight took place on October 21, 1973 and flew roughly 300 meters above the ground for around nine to fourteen minutes. At the time of Brdischka's first electric flight, the world was experiencing the first major oil crisis, thus the flight attracted considerable public interest. Wolf (n.d.)

In the 1970's, solar technology and NiCad battery technology were being developed in earnest. In 1979, the first solar-powered manned aircraft was first introduced and flown. Numerous unmanned research aircraft have been developed to explore this technology. NASA's Pathfinder, Pathfinder Plus, and Helios were developed between 1985 and 2001. These aircraft set a number of altitude records for solar-powered, propeller driven aircraft. Another unmanned solar aircraft, called the QinetiQ Zephyr set an endurance record of over 336 hours in July of 2010. Dunbar (2015) Possibly the most noteworthy feats of a solar powered aircraft was the manned circumnavigation of the Earth by the Solar Impulse II. The Solar Impulse II departed Abu Dhabi, United Arab Emirates (UAE) on March 9, 2015 and returned to Abu Dhabi 16 months later on July 26, 2016. The 26,000 mile flight was the first circumnavigation of a manned fixed-wing aircraft on solar power alone. Around the world to promote clean technologies. (2016).

Electric aircraft traditionally have been light aircraft until only recently. This is primarily due to battery technology as the limiting factor. Heavy batteries have been prohibitive for large payloads. Many experimental and research designs have been flown resulting in the development of light recreational and pilot training aircraft. Some legacy piston powered aircraft like the Cessna 172 have been retrofitted with an electrical propulsion system. The light aircraft market segment is an excellent starting point to test systems and prove the viability of electric aviation. Because of this, Siemens and Airbus have also tested light fully electric aircraft to help further the technology.

III. Overview of Electric Aircraft Technology

Electric motor technology has been around for nearly 200 years and excels at converting electricity into rotational power. Most of the potential energy available in the fuels used in piston and turbine engines is lost to heat. Electric motors only lose a small portion of their potential energy from electric resistance. Conversely, an electric drivetrain can operate at higher than 90% potential energy to the shaft. A turboprop is capable of 20-25% potential energy for short low altitude flights increasing to 35% efficiency at high altitudes. Turbofan engines are quite efficient but not at the level of an electric motor. Electric motors are digitally controlled allowing them to be more reactive to pilot input. These motors are able to go from idle to full power much quicker than a piston or turbine engine. Another benefit of electric motors is their ability to be scalable and still maintain the same efficiency notwithstanding the size of the motor.

Turbine and piston engines rely on burning fuel and require contact between mechanical components within the engine. This generates both heat and wear, limiting the engine's life. Electric motors have relatively few moving parts, which means there is far less wear and tear, as well as less maintenance compared to traditional aircraft engines. Aircraft used by regional airlines would benefit from the reliability and the long service life of electric propulsion motors. All of these factors add up to the potential for reduction in maintenance compared to conventional aircraft engines, as well as reduced unexpected repairs.

Electrification of aircraft currently exists in two segments in the aviation industry, Electrical Propulsion and More Electric Aircraft (electrification of certain aircraft systems).

Types of Electric Propulsion:

Pure Electric Aircraft

Pure electric aircraft are aircraft powered only with electrical propulsion. The power is derived from a battery or another source of electric power. Electric motors lend themselves well to aircraft propulsion because they are able to operate on a wide spectrum of revolutions-per-minute and are highly reliable. Because they are easily adaptable, electric motors may be able to replace turboprops and turbofan engines as battery technology improves.

Hybrid-Electric Aircraft

Hybrid-electric aircraft, much like hybrid cars and trucks, are powered with a combination of electricity from batteries and an internal combustion engine. There are two types of hybrid-electric aircraft configurations, series hybrid and parallel hybrid. Series hybrid aircraft use electric motors for propulsion and the internal combustion motor drives a generator to produce supplemental electricity for the electric motors. Parallel hybrid aircraft use both the internal combustion engine and the electric motor for propulsion of the aircraft.

Turbo-Electric Aircraft

Turbo-electric aircraft take kinetic energy from a turboshaft to drive an electric generator. The generator is then used to power electric motors to generate propulsion. Turbo-electric propulsion gives designers added flexibility to place propulsion fans in locations to create a very efficient aircraft. This particular design utilizes electric propulsion but is still reliant on fossil fuels or other fuel sources.

More Electric Aircraft

Throughout the development and evolution of aircraft, systems such as control actuation, de-icing, and cabin climate control, have been powered with mechanical, pneumatic or hydraulic power. These systems have been powered by the aircraft's engines that are also being used to propel the aircraft. Because the aircraft's primary powerplant is powering all of these systems, there is a reduction in power and reduced efficiency. As electrical systems and electricity generating capabilities have evolved, older systems that rely on the aircraft engines for mechanical or pneumatic power can now be provided with the use of electric motors. Flight controls, cabin climate control, thrust reversers, wheel brakes, de-icing and other aircraft systems are being powered by electric motors and actuators. Because of this technology advancement, the powerplant generating the aircraft's propulsion can operate at peak efficiency because it is driving just a generator and is no longer being used to power the other aircraft systems.

IV. Electric Aircraft Functional Areas

a. Manufacturing/Certification of Electric/Hybrid-Electric Aircraft

The certification of any aircraft is a complicated process. Aircraft certification requires the manufacturer to demonstrate that the aircraft they are developing meets the safety standards set forth in the standards for small aircraft and transport aircraft. Electric and hybrid-electric aircraft certification will provide challenges to manufactures and the Federal Aviation Administration (FAA) alike. Developing technology of any sort poses issues for a rigid and exhaustive certification process. Because challenges exist for a rapidly changing technology area and for novel configurations, it is unclear which existing regulations, or new regulations would be required for certification.

The two main categories that the electric aircraft under development would be certified under are 14 CFR Part 23 and 14 CFR Part 25. Part 23 certification standards are for small aircraft with a maximum takeoff weight (MTOW) less than 19,000 pounds and carry less than 19 passengers. This certification standard was recently rewritten to allow for a streamlined process to introduce new technology and speed up the certification process which could potentially reduce the cost of aircraft certification. The General Aviation Manufacturers Association (GAMA) called the new rule "a true breakthrough for the light end of the general aviation sector. Rather than having to comply with overly prescriptive design requirements, manufacturers will now be able to more nimbly respond in a cost-effective manner through performance-based airworthiness safety rules and consensus standards for compliance."

Part 25 certification standards are for transport category aircraft defined as; Jets with 10 or more seats or a maximum takeoff weight (MTOW) greater than 12,500 pounds; or propeller-driven airplanes with greater than 19 seats or a MTOW greater than 19,000 pounds. Part 25 has more stringent requirements to which manufacturers must adhere to and undergo scrutiny lengthier certification process over aircraft certified under Part 23.

A challenge to the manufacturing and certification of electric and hybrid-electric aircraft is industry experience, and experience of the regulatory authorities (e.g., FAA). Most of the parties seeking certification and planning to produce electric/hybrid-electric aircraft are new entrants in the field of aviation with limited experience in certification and manufacturing. Fortunately, many have ties to established aviation industry that will provide guidance. For regulators, the challenge will be to establish new standards for new and novel designs that establish the level of safety consistent with existing standards for the category of aircraft, and to do so in a timely manner. There currently exists a lack of relevant standards for high performance batteries and electrical components in propulsion systems (electric and hybrid) in the aircraft environment.

The FAA bases their certification procedures on a five-year certification program for transport aircraft following application and a three-year program for other aircraft, but even the well-established, most experienced applicants typically exceed the five-year timeframe. One applicant, and other potential applicants, have proposed designs that are typically entirely new aircraft with novel systems (i.e., electric propulsion, fly-by-wire flight controls, tilt rotors, etc.). Due to this, the certification timeframe would likely be longer than a typical aircraft of today. Manufacturers are mitigating these challenges by working closely with the FAA.

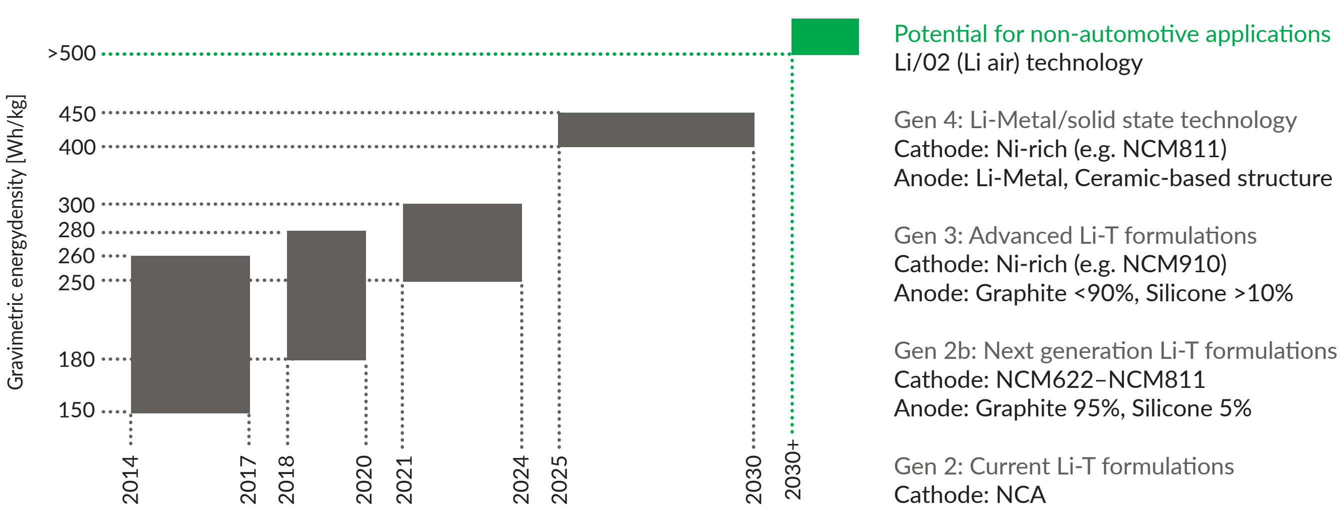
Applicants for type certification and production certification benefit the most from well-developed, detailed plans coordinated with the FAA. Regular updates to the plans and meetings between the applicants and the FAA are essential. Engagement with the FAA should occur in the early stages of design and development so that the FAA can develop the appropriate airworthiness standards for the aircraft, and the applicant can adjust their design to comply with established or expected regulations with as little impact to their program schedules as possible. Also, more engagement by the applicants in ASTM International (formerly known as American Society for Testing and Materials) consensus standards would quicken the development of these standards which are used for compliance with the regulations.

The airframe manufacturing of electric and hybrid-electric aircraft is not markedly different than conventional aircraft. Designers have a number of very reliable construction methods such as composites and traditional aluminum that have been used with great success for decades. Manufacturers such as Zunum Aero are creating designs with a relatively simple airframe to minimize the complications rather than going with a complex design. However, manufacturing of hybrid and all electric airplanes may have significant differences from traditional airplanes. Integration of batteries and cooling systems on the aircraft for optimization will present new challenges. Distributed batteries, distributed motors, higher voltages, aerodynamic considerations, wiring, among other challenges may require unique manufacturing techniques. These things can only be discovered within the context of a full-scale development program.

One of the keys to making electric and hybrid-electric aircraft a reality is the ongoing development to increase energy density of battery technology. Jet fuel has an energy density that is 6 to 8 times higher than a 500 Wh/kg battery. High battery storage capacity and light weight batteries are critical to fully electric and hybrid-electric aircraft. In order to accommodate a commercially viable payload and range, batteries will need energy density of 500 Watts per Kilogram

Roadmap for Lithium-Ion Battery Technology [Wh/kg]

Projected automotive roadmaps indicate batteries will only reach the 500 Wh/kg level required for aerospace after 2025.



Source: Roland Berger

(Wh/kg). The current range is 150-250 Wh/kg well short of the 500 Wh/kg needed for larger passenger aircraft. Roland Berger (2017) Battery technology is advancing at a rate of 8% increase in energy density per year. Reimers (2018) By the mid-2020's rechargeable Lithium batteries will be produced with an energy density of 400-450 Wh/kg. Roland Berger (2017)

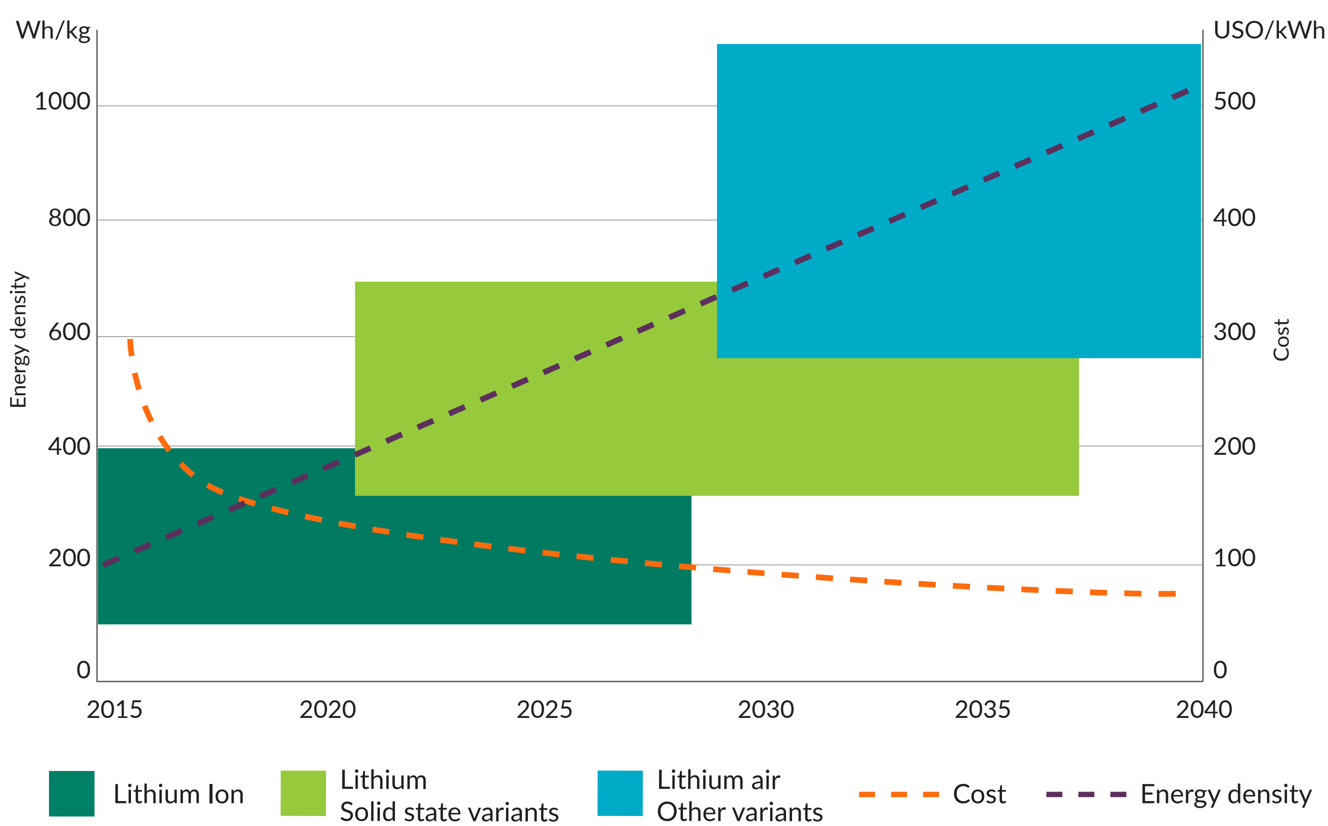
Battery technology is currently being driven by the electric car industry. Demand for electric vehicles is increasing and shows no sign of slowing. That market will in turn drive the demand for advancements in battery technology in terms of energy density as well the ability to rapidly recharge. Solid state batteries are predicted to be the next step forward in battery technology. However, near term demand for batteries has prompted some manufacturers to focus on expanding the capabilities of existing or traditional battery technology.

Specifically, challenges exist with the batteries systems which drive the electric propulsion. Many new entrants in this field are proposing aircraft that have substantial power requirements and thus large batteries or many smaller batteries which may have to comply with existing safety standards such as RTCA DO-311A.

b. Airline Operations Using Electric/ Hybrid Electric Aircraft

Electric and hybrid-electric aircraft have the potential to turn back the clock on regional air transportation. With the promise of lower operating costs and increased efficiency of electric

Battery Technology and Cost Scenario 2020–2040



Feasibility study by GREEN FUTURE AS

	CARS	AIRCRAFT
LIFETIME	Design lifetime of a car, typically 6 years and 200,000 km, is less than 1,000 cycles. Requirements for commercial road transport and all-day autonomous driving may change this figure	A commercial regional aircraft may fly more than 10 hours every day. Will aim for at least 5,000 cycles
SAFETY	Important	More important than on the ground, given that failure in mid-air would be catastrophic. Safer battery chemistries, while more expensive up front, could save costs on battery enclosure and ventilation for extra safety from less stable chemistries and designs
COST	Very important. The car industry will propel low-cost solutions	The ideal battery for commercial aircraft will serve a longer duty. Costs for aircraft batteries are directly related to lifetime and may accept significantly higher initial costs if lifetimes are longer
SECOND USE	Automotive industry is already for second use. Preferably, the initial design of battery modules fits directly into applications for second use without any modifications	Likely to be similar opportunities for aircraft batteries

Source: Avinor

aircraft technology, this developing industry brings opportunities and challenges to airline companies and startups alike.

Airline companies have moved away from prolific regional commercial air service because they haven't been able to make these routes profitable in the past. Operating costs of legacy regional aircraft and regional airline operations made routes unprofitable. Airline companies moved to a hub airport to hub airport business model with larger aircraft that could operate profitably and in turn drastically reduce the service to small regional airports. Many airports lost air service all together. Because of this, 96% of air traffic are operating from 1% of the airports and 96% of trips that could have been made on a regional aircraft are being made using ground transportation. Zunum Aero (2018)

Electric and hybrid-electric aircraft have great potential to operate out of airports that have substantially shorter runways than traditional regional airliners. Regional aircraft have gotten larger and larger as airline routes and destinations have been consolidated. This made it more profitable to operate high capacity larger aircraft.

These aircraft in turn need more runway length for takeoff and landing. Conversely, because of the current limitations of electric aircraft propulsion, these regional aircraft are smaller in size requiring less runway for normal operations. Zunum Aero's ZA10 aircraft is projected to be able to operate from a runway of 3,000 feet or more. Electric aircraft propulsion lends itself well for STOL (Short Take Off and Landing). Electric motors can be used to produce short bursts of large amounts of thrust to get the aircraft off the ground quicker. The motors can also be reversed on the landing touchdown to provide additional braking to slow the aircraft. Other electric aircraft designs that incorporate vertical takeoff and landing technology such as a tilting wing and distribution of propulsion sources reduce the need for long runways even further. With the capability of operating from shorter runways, air carriers would have the potential to provide service to a greater number of airports around Washington State, the region, and the United States.

Aircraft Size

Many of the electric and hybrid-electric aircraft that are under development and projected to be in service in the next 5 to 10 years are smaller in size and passenger capacity. These aircraft are projected to have a seating capacity of 9 to 19 passengers. This would be a major change from the regional aircraft that are in service today such as the Bombardier Q400 (82 to 90 passengers), the CRJ Series (66 to 104 passengers), and the Embraer ERJ Series (37 to 50 passengers). Due to the limited number of passengers that the electric and hybrid-electric will initially be able to carry, they would be well suited for use as on-demand/air taxi or charter type operations.

Cost/Market Demand

The cost of operating electric and hybrid-electric aircraft is likely to be reduced upon introduction of the aircraft into service. However the overall operational cost of these aircraft will be hard to determine until they have been in service for some time. As the technology is further developed, it is anticipated that these new aircraft may be initially priced marginally higher than comparable turbine or piston powered aircraft. Additional costs to cover infrastructure related costs and training of personnel are also possible. Presently, there is little information available to quantify costs related to electrical energy consumption by electric aircraft.

As discussed earlier, regional airlines are operating relatively high capacity aircraft of 50 to over 100 passengers. Electric aircraft manufactures will have to change the mindset of how regional airlines do business and provide them with a value proposition that makes financial sense. Startups and existing charter operators may see the benefit of the projected lower operational cost of these aircraft and adopt the technology quicker than a major airline. Even still, these aircraft will have to demonstrate their utility and economics above emission reduction to entice businesses to adopt these aircraft.

c. Airport and Infrastructure Requirements of Electric/Hybrid Electric Aircraft

Electric and hybrid-electric aircraft present new infrastructure requirements at airports as well as increased demand at the airport. As a result there will be an increased demand on the utility infrastructure supplying electricity to the airport. This developing technology also has the potential to bring air service to airports that have lost service in the past and open up new markets at airports and communities that have never been served with commercial flights.

The key component to the operation of electric and hybrid-electric aircraft is electricity. The electric utility and electrical supply infrastructure requirements are dependent on the expected electrical loads these new aircraft will demand. Lighter loads may require adding small transformers while larger loads may require the construction of a new substation depending on the level of charging.

Electricity demand also depends on how the aircraft are operated. The time required for charging depends on the battery capacity, state of charge, and time available to charge. If the operator of the aircraft requires the aircraft to be fast charged, this may require a DC fast charger, (electric supply with 3phase, 480VAC, 100A = 50kW delivered power). Fast charging will require a charging facility to be built at airports to service electric aircraft. This would require special equipment to safely connect the charging link to the aircraft in all types of weather. If the aircraft is capable of a battery swap, the depleted batteries would be charged more slowly. Slower charges over many hours could be done with single phase supply power at 240VAC, 30A = 7.2kW delivered power. Slow charging would also require a charging facility to be built to charge and store batteries to make available for expected flights. Existing electrical infrastructure may be difficult to upgrade. For example, old switchgear upgrades, asphalt and concrete cutting/patching can also very expensive for airport sponsors.

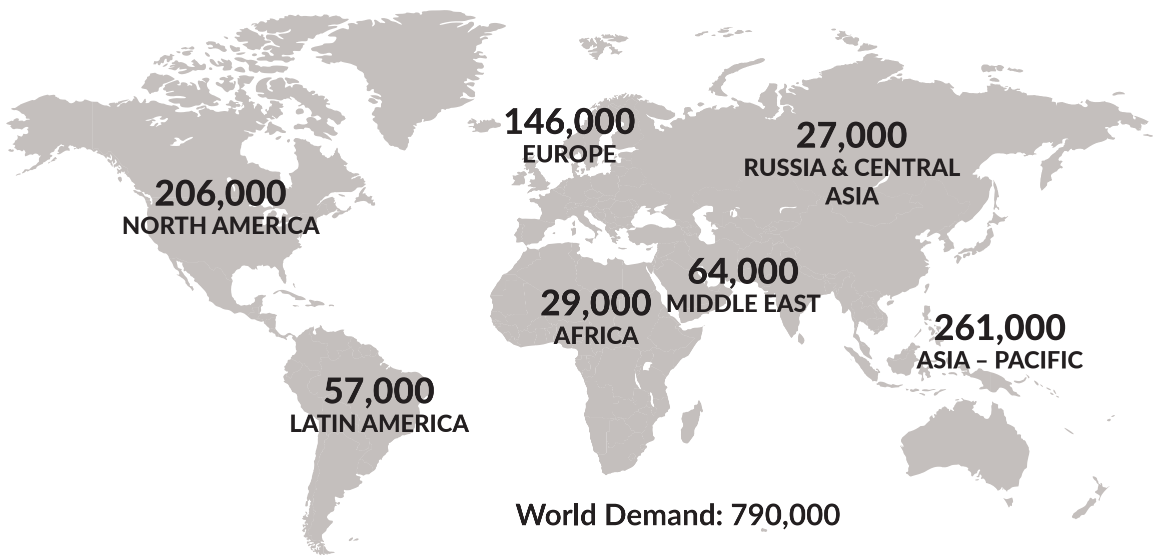
As mentioned in the airline operations section of this report, electric and hybrid-electric aircraft for regional commercial use are capable of operating from runways of 3,000 feet and up. This is due to their size as well as the ability of electric propulsion systems to provide short bursts of power on takeoff to get the aircraft airborne quicker as well as the motors ability to be reversed and used for braking to land in a short distance. Currently out of Washington State's 134 public-use airports, 70 of those have runways of 3,000 feet or more in length.

Of those 70 airports, 60 currently do not have commercial air service. These airports are spread throughout the state and serve the aviation needs of nearly every corner of the state. Being able to accommodate commercial service from these airports means that airports may not have to spend their airport improvement funds on costly and in some cases, impossible runway extensions. As an example, some airports that have land-use constraints cannot be lengthened because they are surrounded by developed property. Electric aircraft would help alleviate some of these concerns and constraints facing some airports.

Expanded air service will require passenger facilities to handle the traveling public flying from the airport. Most smaller airports were not built with commercial air service in mind and do not have the passenger facilities such as passenger waiting areas, gates, baggage handling equipment, ticketing and check-in areas, as well as TSA security checkpoints. Many of these requirements are a dependent on how the air carriers operate and the destination of the flights. As discussed in the Airline Operations section, this will depend largely on whether the flight is conducted under Part 121 or Part 135. For Part 121 and scheduled Part 135 operations with commercial service destinations requiring passengers to enter a secure area, there will be a need for security screenings for passengers and baggage. For those operating under Part 135 in an on demand air service setting that travels to airports that do not require passengers to enter a secure area, the requirements for security screening and passenger handling infrastructure would be greatly reduced. In an on-demand or charter type operation, the aircraft operator may be able to utilize existing Fixed Based Operators (FBO) to pick up and drop off passengers at airports. However, if the volume of passengers increases, additional facilities may need to be constructed.

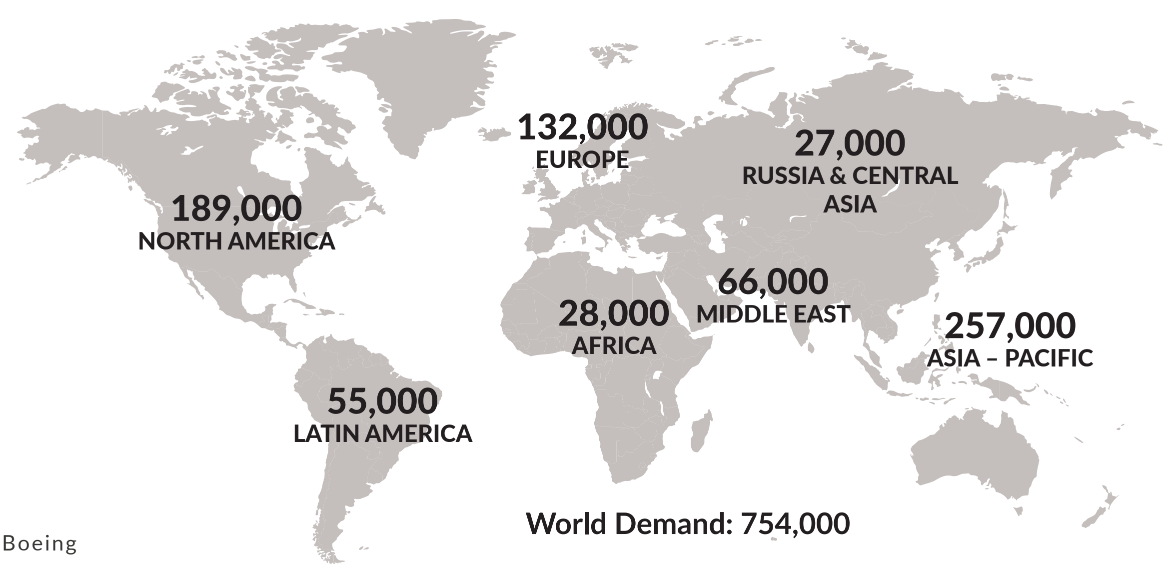
Because of the unknowns associated with this developing technology some infrastructure requirements are not yet fully understood. Additional infrastructure requirements are likely

Pilot Outlook by Region Map
New Pilot Demand 2018–2037



Source: Boeing

Technician Outlook by Region Map
New Technician Demand 2018–2037



Source: Boeing

to be identified as the technology becomes more prevalent. Manufacturers of electric and hybrid-electric aircraft and companies operating these aircraft need to work with airport managers, airport engineering and design firms, electric utilities, and other stakeholders to plan ahead and identify infrastructure needs to be able to smoothly implement and integrate the electrification of aircraft into the Washington Aviation System.

d. Workforce Development Necessary to Support Electric/ Hybrid Electric Aircraft

The aviation industry in general is in the midst of one of the most serious shortages of pilots and aviation maintenance technicians in recent history. The demand for these trained professionals has been increasing over the past decade and is impacting the entire aviation industry. Aviation industry leaders such as airlines, manufacturers and the military are all facing the challenges of the shortage and acknowledge its severity. Manufacturers and potential operators of electric and hybrid-electric aircraft will no doubt face the same challenges that are facing the aviation industry as a whole.

Electric and hybrid-electric aircraft hold the promise to increase regional air transportation which will increase the demand for aviation professionals. More demand for air travel means additional aircraft being manufactured and developed to meet that demand exacerbating the shortage of aviation professionals. To get a sense of the scale of the shortage of aviation professionals, the Boeing Company created a report that forecasts the demand for pilots and maintenance technicians providing valuable insight to the anticipated demand. The Boeing Pilot Outlook forecasts, from 2018-2037, there will be 790,000 pilots and 754,000 technicians needed to meet the projected worldwide demand. Boeing (2018)

While the aircraft maintenance technicians, maintaining and manufacturing electric and hybrid-electric aircraft, will be working on leading edge aircraft technology, they will also require many of the same skills as conventional aircraft technicians. Some airframes under development at this time are very similar to a Pilatus PC-12 or a Beechcraft King Air. However, the propulsion system will be the first of its kind in the aviation industry. Aircraft designers are working to make their design as similar to existing aircraft to minimize the amount of retraining needed to maintain their aircraft. Hybrid-electric aircraft will require maintenance technicians to possess today's skills for working on turbine engines. Fully electric and hybrid-electric aircraft will need aircraft maintenance technicians with additional training and skills to work on electric powerplants and batteries. In addition to maintenance of the aircraft, developing new procedures for handling aircraft batteries will be an important facet of maintainer responsibilities

Aviation maintenance technician schools and industry will need to dialogue to determine the future maintenance needs of these aircraft and the skills technicians will be required to possess in order to successfully work in the electric aircraft field. FAA standards for maintenance technicians lag behind the industry. It would serve manufacturers of electric aircraft well to work with maintenance technician schools in the state and around the country to develop standards that will be needed to work in this field.

Additionally, given the need for aircraft pilots and technicians, the electric aircraft industry will need to provide competitive salaries in order to draw individuals to the industry and retain them. With the airline and aircraft manufacturing industries increasing their wages, this may prove challenging for a newcomer to the aircraft industry.

e. Emissions and Public Acceptance of Electric/Hybrid Electric Aircraft

Energy Consumption and Emissions

Fuel has traditionally been a very large expense for airlines and on-demand charter operations. Commercial aviation is a highly competitive environment requiring air carriers to take measures to keep costs down. This has resulted in industry pressure on aircraft and engine manufacturers to produce more efficient, lower operational cost, aircraft. As the next generation of aircraft are introduced, they are becoming increasingly fuel efficient. Another factor is government and societal pressure urging air carriers to reduce greenhouse emissions.

The aviation industry has taken note of the expansion and success of battery technology in the automotive industry and is developing aircraft to take advantage of electric propulsion. There is no doubt that electric propulsion is more efficient than traditional combustion engines. Depending on the aircraft and flight profile, electric motors are 20% to 40% more efficient than turbine or piston engines. Electric aircraft are also more efficient in other modes of operation such as taxiing and descent. Electric motors can also be used for power regeneration during the descent phase of flight to replace some of the power used during the climb and cruise phases.

Electric motors are understood to operate at 85% to 90% efficiency for use in an aircraft propulsion function. Reimers (2017) A major benefit of electric motors is they maintain the same high level of efficiency regardless of motor size and cruising altitude. This makes electric aircraft as efficient on short haul flights as they are on long haul flights. Conversely, piston and turbine engine's efficiency are often tied to the altitude they are being operated. Lower altitudes being the least efficient and higher altitudes being the most.

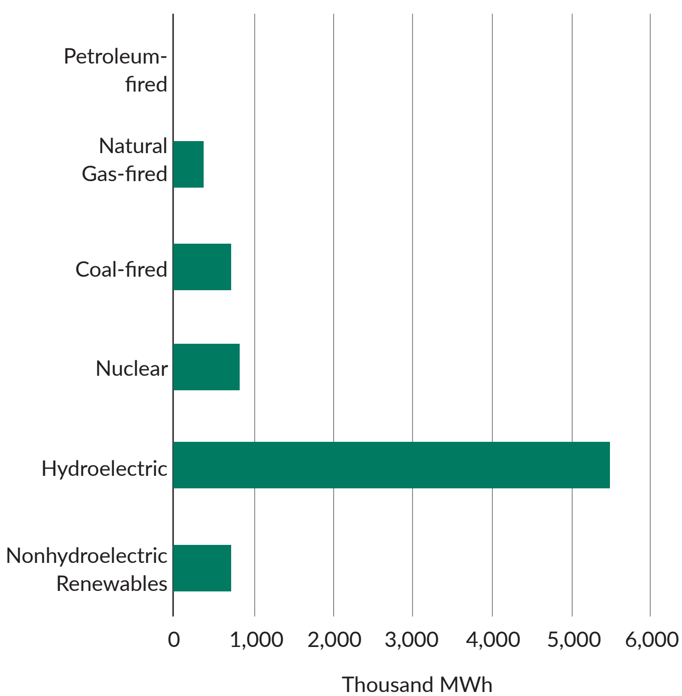
Electric and hybrid-electric also promise a reduction in greenhouse gas emissions. Reduction in fuel consumption and emissions for hybrid-electric aircraft will depend on how much of the flight is powered by batteries versus the onboard turbine generator. It is expected that even hybrid-electric aircraft will be more fuel-efficient compared to existing aircraft of the same class. Fully electric and hybrid-electric regional aircraft of 12-80 seats will be well suited for short 30 minute flights at 280 to 400 mph. The battery will account for over 25% of the takeoff weight of the aircraft. A 50 seat, 20 ton, fully electric aircraft may require a battery that weighs in at 5 tons. Hybrid-electric aircraft would require a smaller battery.

Total greenhouse gas emissions from purely electric powered aircraft will be dependent on the source of power for the electrical power grid. The associated operational costs for the aircraft are impacted by that source of power. Rather than paying aviation fuel companies for jet fuel, air carriers will now be paying electric utilities. The cost for the electricity to recharge the batteries will depend on the utility rates in the location in which an aircraft is being charged.

As electric and hybrid-electric aircraft transfer energy demand from aviation fuels to local electric grids, the reduction of fossil fuel dependency will depend on the electric grid mix. Currently, Washington State generates a significant portion of its energy from hydropower. Seventy six percent (76%) of the power produced in the state comes from renewable sources. U.S. Energy Information Administration (2018) Charging aircraft batteries from the Washington electric grid will reduce dependency on fossil fuels and other imported energy sources. The level of reduction will depend on the penetration of the electric aircraft technology into the market, and the energy sources used to supply the additional electric demand. It is possible that airports could incorporate solar technology, where feasible, to help reduce the environmental impact even further. While not included as a primary point of discussion during the electric aircraft working group meetings, it should be known that alternative fuel sources such as hydrogen fuel cells are a potential supplement or replacement for batteries in the future. At the time of this report, batteries are the most likely near term replacement for fossil fuels given advancements and research in battery technology.

Another factor that could impact both emissions and congestion is the substitution of auto trips for air trips. The benefit is two fold as air travel is more efficient than automobile use and the conversion of conventionally powered car miles to electric based aviation miles aids is reducing emissions. Use of electric aircraft in regional cargo transportation could also contribute to a reduction of emissions as well as congestion on roads between cities.

Washington Net Electricity Generation by Source, Nov. 2018



Source: Energy Information Administration, Electric Power Monthly

Battery Lifetime

Battery life is a critical consideration for electric aircraft propulsion. Because weight is of utmost concern, aircraft will need batteries with the highest available energy density able to produce full power at all stages of flight and charge. Battery life will be determined by both the capacity and ability to deliver full power. For electric automobiles, batteries are considered at the end of their life at 75% to 80% reduced capacity. Aircraft may have different standards of what is considered "end of life" for batteries. The need for a sufficient range to account for power reserves and ability to generate full power on takeoff will require different standards than the automobile industry.

With the proliferation of battery usage for electric vehicles and the expected growth of grid-connected batteries for storing electricity produced by renewable sources, the raw materials used to produce lithium-ion batteries can be difficult to source. Lithium-ion batteries are the most common rechargeable batteries currently on the market and are made up of a host of different materials beyond lithium, such as nickel, cobalt, and graphite. An analysis published in the journal Joule in 2017 predicts that in the next 15 years there will be temporary interruptions and slowdowns in the manufacture of batteries due to bottlenecks of key materials such as lithium and cobalt. This has nothing to do with the lack of material available, but is dependent on the political and economic instability in the countries that produce the material. The Democratic Republic of the Congo accounts for more than half the world's cobalt production. The country has a long history of volatile instability stemming from armed conflict and government inconsistencies. Tensions in the region have caused the price of cobalt to nearly double in 2017 and 2018. Reimers (2018)

Another concern is what happens to the batteries once their useful life as an aviation power source is finished. Automotive batteries that have reached the end of their useful life are used in a secondary application as grid storage. Aviation batteries could be repurposed in a similar manner rather than being discarded.

Public Acceptance of Electric Aircraft

Electric and hybrid-electric aircraft promise emission reduction and lower operating costs, but what will this mean to consumers and the flying public? Public acceptance of this technology will be gained by proving the value and safety of the technology and how it can be used to better people's lives.

One way to prove value to the consumer is by reducing the cost of air travel. Electric and hybrid-electric aircraft promise lower operating costs for air carriers, translating to lower cost airfare. For example, the Zunum ZA10 is forecast to cut operating costs by 40% to 80% compared to traditional combustion engine regional aircraft with an operating cost of 8₵ per passenger seat mile or $250 per hour. Zunum also estimates a 400-mile flight to cost approximately one-third of the average cost of a standard airfare. Zunum Aero (2018)

Another potential benefit to the citizens of Washington State is the possibility of increased availability to regional air service. As mentioned previously, these aircraft have the ability to land on shorter runways and require less infrastructure than larger regional aircraft. This, coupled with lower operating cost, has the potential to make air service profitable for air carriers at smaller airports, as well as expanding regional travel for consumers. Increased regional air travel has the potential to cut travel times significantly while reducing congestion on the roadways. For example, a 400 mile trip might take more than 8 hours to drive, but if air service was provided at the local airports, the travel time would be 2 hours and 30 minutes using the Zunum ZA10 aircraft.

Electric aircraft also bring forth the possibility to reduce noise around airports. Aircraft noise is a key concern for communities around busy airports. A portion of aircraft noise is caused by exhaust noise. Electric and hybrid-electric aircraft can reduce and possibly eliminate this noise contributor. Propeller noise is also a larger portion of the noise signature for some aircraft. If the electric or hybrid-electric aircraft is propelled using a ducted fan system, less noise will be produced.

f. Impacts to Washington State of Electric/Hybrid Electric Aircraft

The introduction of electric and hybrid-electric aircraft for use in a regional air service role has the potential to change how the citizens of the state travel and do business. However, this technology may also have an unintended impact on state and local government and provide its own set of unique challenges and opportunities. Electric and hybrid-electric aircraft are forecast to reduce and potentially eliminate the need for traditional aviation fuels. Hybrid-electric aircraft will still rely on Jet-A fuel to operate the onboard electrical generator that powers the electric motors and charges the batteries. However, these aircraft are forecast to use less fuel than traditional aircraft of similar size and passenger capacity. Fully electric aircraft will no longer be reliant on fossil fuels and will recharge rather than refuel at airports. Washington State receives tax revenue from the sale of aviation fuels. A reduction in that tax revenue could have a corresponding impact on state and local government that depend on those revenues to provide services. Below are the state taxes levied on the sale of aviation fuels:

- Aircraft fuel tax – 82.42 RCW (DOL)
- State business and occupation (B&O) tax – 82.04 RCW (DOR)
- Retail sales tax – 82.08 RCW (DOR)
- Hazardous substance tax – 82.21 RCW (DOR)
- Petroleum products tax – 82.23A RCW (DOR)

- Oil spill response fee and oil spill response administrative fee – 82.23B RCW (DOR)

The manner in which electric/hybrid electric aircraft are operated also has a direct impact on Aircraft Fuel Tax revenue. In Revised Code of Washington (RCW) 82.42.030, the following aircraft operators are exempt from paying aircraft fuel tax;

1. Aircraft fuel delivered directly into the aircraft fuel tanks of equipment operated by an air carrier or supplemental air carrier operating under a certificate of public convenience and necessity under the provisions of the federal aviation act of 1958, P.L. 85-726, as amended;
2. Aircraft fuel delivered directly into the aircraft fuel tanks of equipment operated by a local service commuter.

If the aircraft are operated in a traditional airline operation, there would be little tax revenue impact as those operators are already exempt from aircraft fuel tax. If the aircraft were operated in a charter or on-demand manner, they would then be required to pay aircraft fuel tax. If there is an increase in the number of charter and on-demand aircraft operators in the state, the revenue from this tax has the potential to increase. However, if electric and hybrid-electric aircraft start replacing traditional aircraft currently operating in that role, a small decrease in tax revenue could be anticipated.

Another factor to consider with the introduction of electric aircraft in Washington State is funding of infrastructure to support these aircraft. Currently, the WSDOT Aviation Division provides grant funding for airport infrastructure projects around the state. These projects are prioritized primarily to rebuild and/or maintain existing runway and taxiway infrastructure commonly referred to as airside infrastructure. WSDOT awards approximately $1.2 Million per year for these airside projects. However, the current need for airside infrastructure projects is projected to be over $8.4 Million annually. Policy changes to increase the funding for airport infrastructure projects will be needed if demand at local airports increases as forecasted. Electric aircraft technology is also opening up the potential for Unmanned Aircraft Systems (UAS) package deliveries in communities. This will lead to an increase in the number of small cargo feeder aircraft placing an increased demand on the infrastructure at airports in the state. The WSDOT grant procedures will need to be updated to include projects that support the infrastructure needed to charge and service electric aircraft. This could ultimately put the agency in a position to better support innovative technology advancements in Washington State.

Currently, the airline and aircraft charter industries are operated by private companies to bring air service to consumers. A public/private partnership for the aircraft operations portion of the equation could be very costly for the government, but there may be opportunities for partnerships in the development of infrastructure for electric and hybrid-electric aircraft. Charging stations and passenger facilities may need to be built to accommodate electric regional service aircraft at smaller airports. Air carriers or aircraft manufacturers could partner with local governments and port districts to share the costs of the new infrastructure, providing a path forward for increased air service availability.

The technology encompassing electric/hybrid electric aircraft is on the cutting edge of the aviation industry. Early adopters of the aircraft may face challenges in funding given the risks associated with unproven concepts and the associated technology. A contributing factor is many of the companies that will be manufacturing these aircraft are new to the aerospace manufacturing industry. It is also possible that air carriers desiring to purchase these aircraft through a loan will encounter issues in securing the funding. Lenders have trepidation in financing aircraft with companies that are unproven due to the potential risk of the asset not retaining its value. This could be alleviated by government provided down payment assistance or securing the loan for air carriers.

V. Key Findings

a. Increased Access to Regional Air Service

Electric and hybrid-electric aircraft hold tremendous potential to increase regional air transportation in the state and the region. Electric aircraft technology offers lower operating costs compared to conventional turbine and piston powered aircraft. The first electric and hybrid-electric aircraft are anticipated to have 9-15 seats and able to operate from runways as short as 3,000 feet in length. More than half of the airports in Washington State will be able to accommodate these aircraft.

b. Manufacturing and Certification Opportunities and Challenges

Developing, certifying, and manufacturing any new aircraft design is challenging. Electric and hybrid-electric aircraft manufacturers are incorporating new technology and systems into their aircraft, which requires development of regulations and standards by the FAA. Battery technology is one of the biggest factors in the development of electric aircraft capabilities. Currently, batteries are heavy and have a relatively low energy density resulting in smaller sized aircraft. Many of the entrants in the electric aircraft market are smaller startup companies who require sizable investments from outside investors.

c. Infrastructure Demands

Electric aircraft introduction will require infrastructure investments at airports both to support the airside operations as well as the landside infrastructure. Charging aircraft flight batteries requires a tremendous amount of electricity and will require utilities and airports to upgrade their capabilities. The speed of charging will impact the type of electrical infrastructure needed at airports. Not all airports are equipped to handle passenger operations and may need additional infrastructure investment in passenger facilities and amenities.

d. Emission Reduction Potential

Electric and hybrid-electric aircraft are projected to operate at 85% to 90% efficiency, 20% to 40% more efficient than piston and turbine aircraft. Electric aircraft emissions are tied to the electric grid and the source that is generating that electricity. Washington State benefits from obtaining the majority of its electricity from renewable sources. Once aircraft batteries have reached the end of their useful life, they can be reused in a secondary operation to reduce the impact on the environment.

e. Workforce Development and Aviation Professional Shortage

The aviation industry is currently facing a large shortage of pilots and aircraft maintenance technicians. Increasing demand for air travel has exacerbated the need for pilots and technicians. With an added emphasis on regional air travel, more aviation professionals will be needed. Manufacturers of electric aircraft are working to minimize the amount of required retraining for the pilots and technicians operating and maintaining the aircraft. Manufacturers will also need to engage with aircraft maintenance schools to ensure maintenance technicians have the necessary skills to maintain and manufacture electric aircraft.

VI. Working Group Recommendations

The Electric Aircraft Working Group finds that given the potential to expand aerospace manufacturing; open up new markets providing both economic and public benefits; impact the development of the next generation of aircraft resulting in a reduction of greenhouse gas emissions and noise pollution; and provide a regional transportation option that provides relief to congested roadways, continuing to study while working towards the integration of electric propulsion of aircraft is in the best interest of the state.

Funding Recommendation: Provide funding to the aeronautics account for a qualified aerospace consultant to further study the work of Washington's Electric Aircraft Working Group and opportunities for electric propulsion aircraft in Washington State. The study should include the following:

i) Infrastructure requirements necessary to facilitate electric aircraft operations at airports;

ii) Potential economic and public benefits including but not limited to the direct and indirect impact on the number of manufacturing and service jobs and the wages from those jobs in Washington state;

iii) Potential incentives for industry in the manufacturing and operation of electric aircraft for regional air travel;

iv) Educational/workforce requirements for manufacturing and maintaining electric aircraft;

v) Demand and forecast for electric aircraft use to include expected timeline of the aircraft entering the market given FAA certification requirements;

vi) Identification of up to six airports in Washington State that may benefit from a pilot program once an electrically propelled aircraft for commercial use becomes available;

vii) Recommendations to further the advancement of the electrification of aircraft for regional commercial use within the state;

The study and accompanying recommendations should be provided to the transportation committees of the legislature November 15, 2020. The department should also provide a progress report on implementation of recommendations to the transportation committees by February 2021.

WORKS CITED

Aviation fuel sales. (n.d.). Retrieved March 8, 2019, from https://dor.wa.gov/get-form-or-publication/publications-subject/tax-topics/aviation-fuel-sales

Around the world to promote clean technologies. (2016). Retrieved January/February, 2019, from https://aroundtheworld.solarimpulse.com/

The Boeing Company (2018). Retrieved January/February, 2019, from https://www.boeing.com/commercial/market/pilot-technician-outlook/2018-technician-outlook/

Dunbar, B. (2015, August 13). NASA Dryden Fact Sheet - Helios Prototype. Retrieved from https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-068-DFRC.html

Mark, R. (2016, December 20). FAA Releases New Part 23. Retrieved January/February, 2019, from https://www.flyingmag.com/faa-releases-new-part-23

Read “Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions” at NAP.edu. (n.d.). Retrieved February/March, 2019, from https://www.nap.edu/read/23490/chapter/7

Reimers, J. O. (n.d.). *Introduction of Electric Aircraft in Norway* (Rep.). Oslo: Avinor. doi:https://avinor.no/contentassets/c29b7a7ec1164e5d8f7500f8fef810cc/introduction-of-electric-aircraft-in-norway.pdf

Think:Act Aircraft Electrical Propulsion - The Next Chapter of Aviation? (Rep.). (n.d.). London: Roland Berger.

Wolf, M. (n.d.). A journey through the history of electric aircraft – It is almost half a century since the first manned, electrically propelled flight. Retrieved from https://www.arts.eu/journey-through-the-history-of-electric-aircraft

Zunum Aero. (2018, June 13). Lecture presented at Electric Aircraft Working Group Kickoff Meeting in Zunum Aero HQ, Bothell.

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