Battery Swapping for eVTOL

Binghamton University — State University of New York
Binghamton University Scholars Program

Airport Operation and Maintenance Challenge

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1. Executive Summary

Electric vehicle (EV) technology is an alternative energy source that addresses the environmental and economic consequences imposed by continued use of aviation fuels. This technology replaces the fuel-dependent combustion engine with a battery-powered electric motor. In accordance with the most recent vision published by the Federal Aviation Administration (FAA), *Destination 2025*, EV technology holds potential to increase efficiency while minimizing cost and toxic gas emissions with electric vertical take-off and landing (eVTOL) aircraft [1]. Similar to what has taken place within the automotive industry, a shift to EV technology is expected to be adopted by the aviation industry in the coming years with numerous developers presently testing the technology.

Primary concerns surrounding EV technology involve charging and power sourcing. Stationary charging of individual eVTOL vehicles requires significant amounts of valuable infrastructure, time, and energy at the expense of the participating airport. The following proposal investigates a novel means to increase overall charging efficiency and minimize operational costs through use of a battery swapping system. EV aircraft batteries will be remotely trickle-charged either at an off-site location or using available space at the airport in the recommended system. As compared to the current method of rapid charging, trickle-charging lithium-ion batteries will provide greater energy efficiency while improving battery longevity. Charged batteries will be transferred directly to the aircraft by specialized machinery and facilitated by certified technicians. Subsequently, turnover times for charging aircraft will be reduced and the cost of energy will be cut through utilization of charging during off-peak hours.

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3. Problem Statement and Background

As the world continues to release Carbon Dioxide (CO_2) into the atmosphere, the buildup of greenhouse gasses in the atmosphere increases. The emissions of these greenhouse gasses created by humans is causing a global increase in temperature, which in turn reduces snow and ice cover and causes sea levels to rise [2]. Aviation is not exempt from the blame; the global aviation industry contributes to roughly 2.1% of overall worldwide carbon emissions. In 2019 alone, 915 million tons of carbon were released by flights [3]. One of the solutions to this problem would be creating aircraft with an alternative power source. With new technology on the horizon that makes electric vertical take-off and landing (eVTOL) aircraft more feasible, demand within the aviation industry will rise in anticipation of this novel mode of air travel. By switching from carbon-based fuels to electric power, eVTOL could prove to be an environmentally viable solution.

Before this technology can be commercially implemented, there are challenges to be faced and questions to be answered. One of these challenges is the problem of charging the aircraft. Currently, eVTOL aircraft only have enough battery capacity for one short trip. The current standard battery for eVTOL is the Lithium-Ion (Li-Ion) battery, which, at a maximum, has a cell-specific energy of 300 Wh/kg. This is enough power for a 4-passenger eVTOL to make a less than 50-mile trip, according to initial system studies [4]. For these aircraft to be cost efficient, they must spend as much time in the air as possible. Given the current capabilities of the batteries, the aircraft will likely have to be charged multiple times a day.

In the case of electric land vehicles, the widely accepted solution is to set up charging stations where the car will stop and recharge. This does not translate over to eVTOLs due to the large power requirements of the batteries. EVTOL charging stations will require a large amount of power that current infrastructure might not be able to support. Due to the large capacity of the batteries, it will also take over 30 minutes to charge [4].

In their *Destination 2025*, the FAA states that the carbon emissions from aviation are projected to grow in the coming years, and they want to focus efforts on alternative fuel and power sources for aircraft to help reduce emissions. The FAA also wishes to do this in a way which will continue to promote growth for the aviation sector [1]. This means that alternative energy sources will also need to be cost-effective and viable for implementation.

In order to implement eVTOLs in an effective manner, the battery-swapping process must be optimized. In this project, aspects of the battery-swapping process that will be focused on are reducing the time in between flights and reducing on-site requirements for power. This project aims to examine the battery-swapping process to evaluate its usefulness relative to traditional charging methods. With this battery swapping process, we will also show that eVTOLs still meet the proper threshold of efficiency to be implemented. With this in mind, the objectives for this proposal are

- Work towards the FAA's *Destination 2025* goal of reducing carbon emissions by using NextGen technology in a way that promotes growth
- Reduce charging time for eVTOL by using a novel battery-swapping method
- Review literature on batteries used in eVTOL, environmental impact of aviation, and the safety and risks of eVTOL batteries
- Generate a general design for our proposed solution
- Prove its feasibility as a concept for use in the aviation industry

4. Summary of Literature Review

4.1 Environmental Impact

Altering the composition of the atmosphere through aviation emissions, specifically from the combustion of jet fuel, contributes to climate change and ozone depletion. As concerns with climate change have grown exponentially in recent years, the aviation industry bears responsibilities to lower emissions by aircraft. According to *Destination 2025*, the Federal FAA aims to reduce aviation's carbon footprint by investing in new technologies and innovations that promote environmentally sustainable solutions [1]. Shifting away from the use of jet fuel would evidently complete this goal.

Aviation accounts for about 3.36% of CO_2 emissions in the United States. Unless new technologies and policies are put into place, it is forecasted to increase to between 4.4% and 6.2% by 2050 [5].

Jet engine emissions expose both airport personnel and those living in residential areas surrounding airports to a variety of health risks. When inhaled in large amounts, the nano-sized particles emitted from jet engines can be associated with increased risk of disease, increased hospital admissions, and self-reported lung symptoms [6]. A transition to electric batteries would reduce toxic jet engine emissions and would be a viable solution to the Destination 2025 goal.

4.2 Infrastructure and Battery Swapping Process

Electric technology offers a new way to power vehicles by replacing the combustion engine with an electric motor powered by a battery pack and charged by plug-in charging equipment. The purpose of EV technology is to decrease harmful fuel emissions and decrease the cost of fuel for consumers [7].

As an alternative to EV charging, battery swapping could significantly reduce the time and energy required of EV technology in aviation [8]. The infrastructure necessary to quickly swap batteries for electric aircraft and eVTOL air taxis must facilitate swapping the batteries in minimal time while being safe and cost-effective. Currently, eVTOL batteries have a high capacity, but they are heavy. For example, a 200Wh/kg battery on an eVTOL with a range of 150km weighs 600kg. Due to the heaviness of the batteries, they would not be able to be swapped by humans directly [9]. However, the infrastructure must be operable by humans to provide maintenance and emergency services considering malfunctions or errors, such as physical damage or fires [10].

Battery swaps must minimize time and labor to be an effective solution for eVTOL operations. If the battery is fully charged, it is estimated that eVTOL aircraft battery swaps take an average of 15 minutes [8], but according to the Institute of Electrical and Electronics Engineers (IEEE), estimates say that in the future, it will take as little as three minutes for a battery swap and that batteries will have a capacity of 150kWh [11]. Although battery swapping time is estimated to decrease over time, if safety is prioritized, passengers may have to wait in a separate area while the swap occurs to avoid injury, creating an inverse relationship between safety and efficiency [12].

4.3 Safety and Risk Analysis

Figure 1. Pros and Cons of Various EV Charging Methods [10].

Charging Method	Pros	Cons
Battery Swapping	• Currently faster layover times meet a better operational case for aircraft. • Peak power needed could be lower. • Possibly more effective for seaplanes.	• Increased maintenance risks. • Possible damage to aircraft during swapping. • Infrastructure may require more space. • Legal questions on battery ownership when swapping batteries at different airports. • Currently lacks FAA support.
CCS/Standardized Charging	• Known standard already vetted with ground electrical vehicles. • Equipment more readily available and cost effective. • Backward compatible with future technologies.	• Limited by standards to <400 kW charging speeds. • High power charging may have tougher impact on the grid. • Depends on acceptance of this standard by manufacturers and use case.
Proprietary Charging Standard	• Customized per aircraft to suit specific needs. • Could be faster to market or allow for different charging profiles with specific battery technologies.	• Not standardized so different aircraft may not use the same charger. • May cause operational issues as the industry adapts to multiple proprietary methods.

Figure 1 describes the pros and cons of various electric aircraft charging methods. Currently, as seen in Figure 1, the FAA does not yet have standards implemented for electric aircraft in aviation because the technology is still being developed and tested. Although EV technology is well established in the automotive industry, as stated in Figure 1, transferring EV charging to a scale as large as aviation poses a risk to the operational performance of the charging because the aviation vehicles themselves may be too heavy to load on the distribution systems. Based on Figure 1, some significant benefits of battery swapping, compared to charging, include reductions in turnaround time for the aircraft and a lower demand on the power grid reliability. However, there may be a need for more space for the infrastructure required for the battery swap, either on or off-site, which will increase costs and the ownership of the batteries remains uncertain as the eVTOL travels from airport to airport.

Further risk assessments may be done to determine, quantitatively, how electric aircraft will impact electric power systems and their operation [13]. According to the National Highway Traffic Safety Administration (NHTSA), lithium-ion batteries, a major component of EVs, store substantial amounts of electrochemical energy, but that energy could potentially be released in response to failures such as excess heating. Electrochemical hazards are not yet fully understood by the NHTSA and damage can occur to the aircraft during the swapping process, according to Figure 1 [14].

5. Problem Solving Approach

Our team started this year's competition by becoming familiar with both the overall project guidelines as well as the different obligations of the sub teams. After the professors lectured the team on basic airport information to help build a baseline understanding of and grasp certain areas of interest for the competition, the members were each tasked to individually come up with three potential ideas. Once each of the members had pitched their ideas, the professors helped the class to narrow the potential projects down to four ideas through an in-class charrette. This refined list is noted in Table 1.

Table 1. Project Concepts Considered and their Advantages and Disadvantages

Potential Project	Advantages	Disadvantages
Alternative Fire-Fighting Method to Perfluoroalkyl Acids (PFAAs)	Pursuit of this idea would intend to reduce the environmental impact of fire-fighting practices, particularly the contamination by PFAAs.	In order to pursue this idea, the team would need great knowledge of the exact chemistry behind extinguishing fires of different fuels.
Electric Aircraft Fire-Fighting Method	Electric aircraft would run off lithium-ion batteries and would therefore not use traditional jet fuel. Because of this, the fire-fighting foam currently used for aircraft fires would not be effective, and	After initial research on the matter, the team found that lithium-ion battery fires could be put out by flooding the cell with water, and that the amount of water needed to put out a fire for a

	an alternative approach would be needed.	battery large enough to power an aircraft is exorbitant.
Drone Flight Checks	By using drones to perform preliminary FAA Flight Checks, it would cut down the expenses of aircraft test sessions as well as lessen the amount of fuel burned during these procedures.	While research found this area to be unexplored, in the end this proposal was too complex and non-specific to be worth focusing on, particularly with the intricacy of drone programming.
eVTOL Battery Swap	Implementing a Battery Swap procedure would help maximize the life cycle of eVTOL batteries while also increasing the speed of turn-around times. Additionally, such a proposal would be easy to implement across multiple Airports.	While all the research looked extremely promising, some concerns were raised over how little support Battery Swaps already have, as well as some safety concerns regarding swapping procedures.

After deliberating on the final four concepts, the team decided that an eVTOL battery swap proposal was both the most viable and most innovative idea of the various concepts. From there, the team was divided into sub teams to take on different aspects of the project: the Design Team handled the Technical Aspects Addressed and Projected Impacts; the Engineering and Graphics Team handled the Photo Gallery, Problem Statement and Background, Project Cover and the Summary and Conclusions; the Risk Assessment and Research Team handled Appendix A, the Summary of Literature Review, the Safety/Risk Assessment, Appendix E and Appendix F; the Strategies and Approach Team handled the Interactions with Airport Operators, Appendix B, Appendix C and the Problem Solving Approach. It is worth noting that each team helped contribute to the tasks completed by other teams, such as Engineering and Graphics providing photographs for this very section. With sub teams in place and tasks in hand, the class set off to research, design the proposal and arrange meetings with various experts.

Figure 2. Class Discussing Ideas

After an extensive amount of research and narrowing down the team's focus, the final proposal became known as "B-Swap", an eVTOL battery swapping station and procedure. Essentially, after the eVTOL aircraft lands at an airport it would be sent to the Battery Swapping Facility where the current battery would be offloaded and sent to a charging facility, either on airport or at a remote location, while a new battery is loaded on and secured by technicians. After the swap, the eVTOL would be ready for its next departure. In refining the final proposal and understanding the technical aspects and flaws it could potentially have, two expert interviews that were of importance were M. Stanley Whittingham, a Distinguished Professor of Chemistry at Binghamton, and Sam Hobbs, a team member at Beta Technologies. Dr. Whittingham, a Nobel Laureate and leading expert in lithium-ion batteries and one of the technology's inventors, provided the team with crucial facts regarding battery charging and life cycles such as how the FAA requires 20 minutes of battery life remaining in all aircraft batteries upon landing which gave us insight into how discharges work as well as the extent to which charging should go. Dr. Whittingham also affirmed that the trickle charging performed in the proposed procedure would allow for more battery cycles, while the hot temperatures of the batteries after landing would require specialized training of technicians.

Meanwhile, Mr. Hobbs, an employee at a leading innovator in eVTOL manufacturing, voiced potential flaws to the approach as they were related to battery weight, as he informed the team that Beta's batteries are approximately 500 pounds per pack. Mr. Hobbs did, however, make clear that the implementation of a battery swapping approach would be good for the future as the FAA and others will look for the best means to standardize the charging.

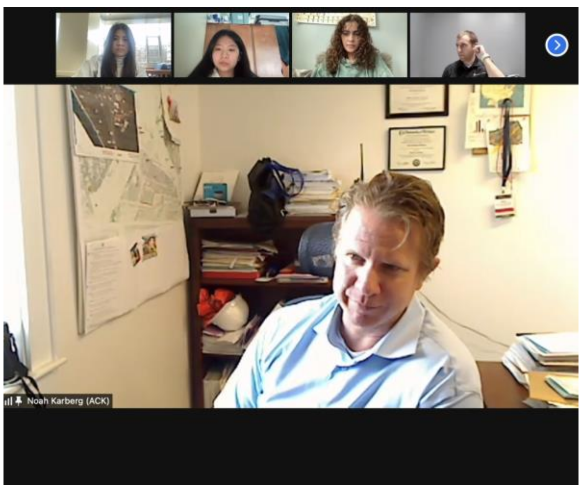
After the eVTOL battery swap has been implemented, there will be a fair amount of maintenance to consider. One industry expert that the team was able to interview was Noah Karberg, Assistant Airport Manager and Environmental Coordinator at the Nantucket Memorial Airport in Massachusetts. Mr. Karberg emphasized the importance of personnel requirements for operating a battery swap to ensure safety. Additionally, he noted the cost to employ a person to run the swapping system would be high and continuous. This would be especially true for smaller airports that would likely see fewer aircraft operation volumes. The value of the worker would be highly dependent on how many eVTOL turnovers the worker can carry out in a given time frame. In addition to Noah Karberg, Brian Smith, P.E., an Aviation Manager at McFarland Johnson Inc, gave the team his input on maintaining the battery swapping operation. Mr. Smith brought the consideration of the machinery needed to carry out the swapping to our attention. Because of the magnitude of the batteries that will be powering aircraft, Mr. Smith foresees the need for specialized equipment to remove and reinsert the battery packs. However,

Figure 3. Class Discussing the Layout of Proposed Design

Mr. Smith claimed that developing this would be a very minor issue that would have a relatively simple solution constrained in more detail by the specifications of the aircraft and battery packs.

In addition to creating the concept, researching the benefits and drawbacks, and considering implementation and maintenance concerns of eVTOL battery swapping, the team needed to research the FAA's guidance on Vertiports and handling lithium-ion batteries. EVTOL machinery and its introduction to the aviation industry are in their infancy, so the official regulations per the FAA are as well. This is rapidly changing, as US and United Kingdom aviation authorities are anticipating eVTOL entering the airspace and are currently working on facilitating the process of certifying and validating eVTOL technology, operations, and personnel licensing [15]. The most current FAA guidelines for eVTOL infrastructure come from a draft FAA Engineering Brief on Vertiport Design. According to this draft, the design for infrastructure of the charging location of lithium-ion batteries should comply with National Fire Protection Association (NFPA) Standards and IEEE 519-2014 regulations [16]. The most recent FAA advisory circular on testing and installation of rechargeable lithium-ion batteries and battery systems on aircraft also provides many guidelines which should be followed, yet many of them apply more directly to the battery manufacturer. The regulations which the team has deemed to apply most directly to the battery swapping operation are that the battery handling follows the guidance provided directly by

Figure 4. Capture of Zoom Call with Noah Karberg



the battery manufacturer regarding storage and monitoring and that battery interfaces are consistently monitored for corrosion and moisture [17].

After each team completed and submitted their sections of the overall design proposal, the Team Leader and subsequently the Professors went through and provided recommended edits and comments to best fit our final report. Once all the components were developed, the report was finalized and submitted to the ACRP University Design Competition.

6. Description of Technical Aspects

6.1 Introduction

As electric aircraft become more prominent, there will be many difficulties concerning charging. One challenge airports face is the charging of batteries in a way that can save time while preserving the longevity of the battery. Engineers must find a balance between decreasing charging times and mitigating the negative impacts rapid charging has on battery longevity. Battery swapping provides a clear solution to these concerns, as it addresses the need to turnaround aircraft in a quick and efficient manner while allowing batteries to be charged in a way that maintains their quality. Through battery swapping, speed and battery health are preserved because they are treated independently.

6.2 Proposed Solution

When an electric aircraft lands, it will first taxi to and park at a location where passengers can safely deplane. Passengers will not be on or near the aircraft when battery swapping occurs, as any possible failure during battery swapping must not put passengers in danger. After passengers have deplaned, the aircraft will taxi over to the battery swapping facility. It will enter the designated area for removing the battery pack, and the flight crew will exit to minimize personnel exposed to potential dangers during swapping.

It is likely that the battery will be swapped from below the aircraft as batteries on aircraft evolve. According to Professor M. Stanley Whittingham, only part of the battery may be swappable as the other part provides structural support to the aircraft. We are operating under the assumption that at least significant parts of the battery system are removable. The body of the aircraft will likely not be elevated high enough to work on, so the center of the floor of the swapping station may be lower than the aircraft as shown in Figure 5 [18]. This allows technicians to be under the floor to access the aircraft's battery. Using an electric dolly to support the battery, such as one shown Figure 6, the current battery will be removed and loaded onto a vehicle for transport [19]. The vehicle will take the pack to another location depending on the airport's capabilities and needs. For airports that can build the required charging infrastructure on-site, the battery packs would simply be transported to the charging site. Airports that are unable to dedicate space to charging infrastructure or can cost-effectively generate the necessary power may load the battery packs into trucks and transport them off-site to a separate charging facility.

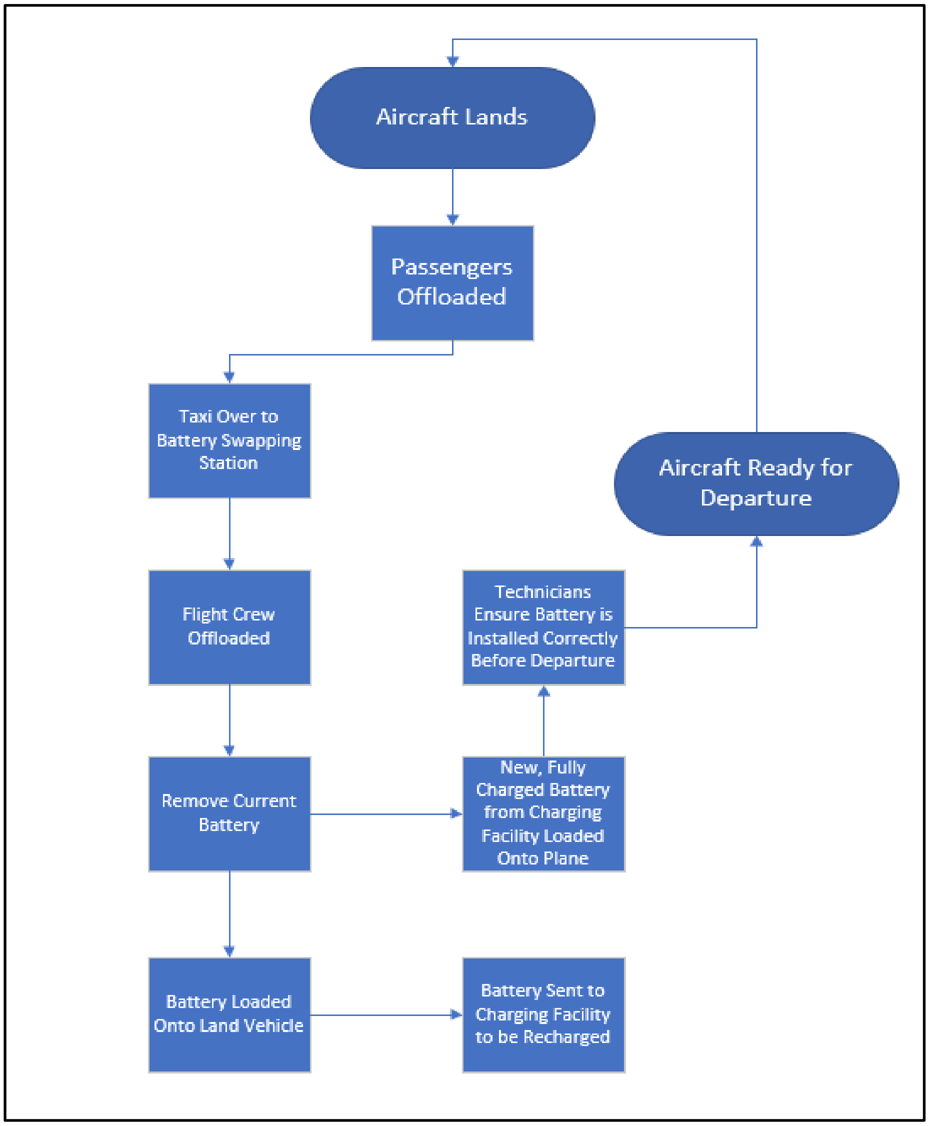
Figure 5. An Example of the Open Floor That Will Be Implemented in the Battery Swap Station [18].

Figure 6. An Electric Dolly for Engines, Similar to That to be Used in Battery [19].

With the depleted battery out of the aircraft, a fully charged battery would be ready to be installed immediately with the same electric dolly. The swapping job would be completed by a certified technician and then checked by a certified inspector and tested electronically to ensure the battery is securely mounted in the aircraft without electric issues. Once inspected, the aircraft would then be pulled out of the battery swapping station via tug and then taxi to pick up the next set of passengers at another location. The aircraft would then be ready for its next flight with a fully charged battery. This process is shown as a picture in Figure 7 [20], and as a flowchart in Figure 8.

Figure 7. A Battery Being Taken out of an Electric Aircraft [20].

Figure 8. The Battery Swapping Process.



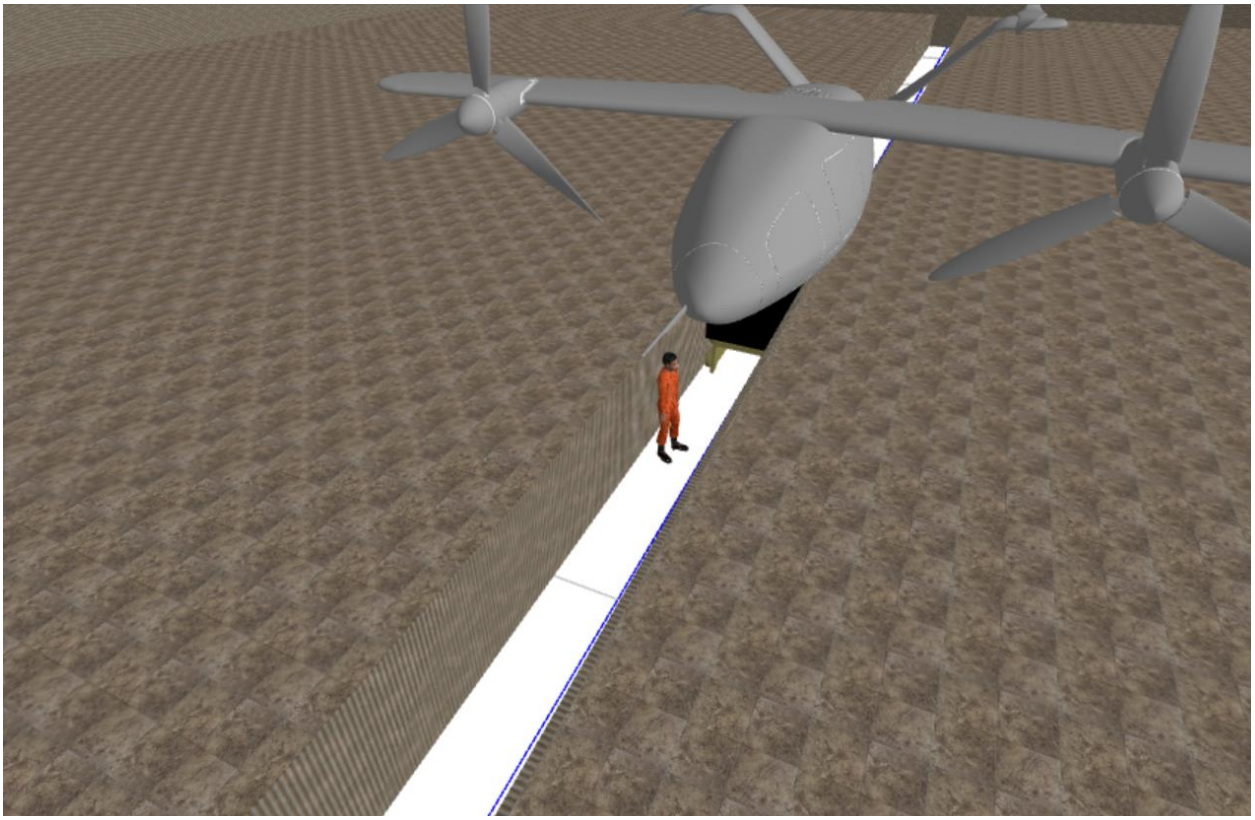
6.3 Infrastructure Requirements

The battery swapping station will be able to support multiple types of electric aircraft, including electric commercial jets and eVTOLs. The capacity of the battery swapping station will depend on resources allocated by the airport. Ideally, the battery swapping station will be large enough to accommodate all electric aircraft on the ground such that there is no delay in schedule.

If the battery charging facility is constructed on airport grounds, it will be a separate building ideally near the battery swapping station. If the charging occurs at a location that is further away from the battery swapping station, a facility to store the charged batteries should be constructed near the battery swapping station. Having the charged batteries near the battery swapping station so that batteries can be quickly transported for installation. Separating the buildings will minimize damages if a battery catches fire in the battery charging station. Likely, the swapping process will be carried out by a private entity separate from the airport on land leased to it from the airport, however, this could be considered as a service offering for airport operators, as well. The charging will also likely be carried out by the same entity that completes the swapping process, and will occur on-site, if possible, but could occur off-site if space or power constraints require it. This part is analogous to the current refueling and basic maintenance process, which is often carried out by private contractors, airline employees, or airport staff.

The battery charging facility needs enough power to fully charge electric aircraft batteries over an extended period (such as overnight). To preserve the lifespan of the batteries, a slow charge rate will be used, and the number of batteries being charged at once will depend on the airport. To charge a single 150 kilowatt-hour (kWh) battery in 13.5 hours, a 400-volt (V), 3-phase, 11.1 kilovolt-ampere (kVA) power system would be required to charge the battery at 16A [21]. For reference, some of the most powerful superchargers used today for electric cars deliver currents of up to 500A during the charging process [22]. A sample rendering of the interior of the battery swapping station is shown in Figure 9.

Figure 9. The Battery Swapping Station.



6.4 Battery Swapping and Transport Requirements

The weight of electric aircraft batteries must also be considered for their swapping and transport. An eVTOL with a range of 150 km will require a 200 Wh/kg battery that weighs 600 kg or a 157 Wh/kg battery that weighs 475 kg [9]. The machine(s) used to swap the batteries must be able to hold the battery weight. Ideally, the vehicles used to transport the batteries will be able to carry multiple batteries at once. The machinery used to remove, and re-install batteries must be mobile in order to service a variety of aircraft.

Initial concepts for the removal will likely include an employee undoing any features that secure the battery in place, such as bolts or straps. Other parts of the process would involve securing the battery to the machine before lowering it from the aircraft, possibly through straps, platforms, hydraulic claws, or other mechanisms. The installation process would be very similar but in the reverse order. Later iterations of the machine may be fully automated to make the processes more efficient.

6.5 Proof of Concept

Battery swapping is widely used for electric cars in China, as depicted in Figure 10. The electric car is driven into a battery swapping station where a spent battery is swapped for a fully charged battery. The process is automated in newer facilities, and swapping times are only a few minutes [23]. One Chinese company, NIO, already has a network of over 700 swapping stations, while other companies such as Geely, and even Honda, are planning to get in on the swapping idea in some capacity. Some startups in the U.S. are also starting swapping programs, such as one associated with Uber in California [24]. By applying the knowledge gained from electric car battery swaps to electric aircraft battery swaps, turnaround times can be shortened, and greater efficiency achieved.

Figure 10. A Battery Swap in an Electric Car [25]

7. Safety Risk Assessment

While battery swapping has the potential to be a significant improvement over more traditional charging methods for eVTOL aircraft, there are still risks that should be considered in the process. According to the FAA Advisory Introduction to Safety Management Systems (SMS) for Airport Operations (FAA Advisory Circular 150/5200-37), someone should be identified as a Safety Manager who will oversee the development and maintenance of the SMS, report to higher management, and distribute SMS information to airport staff as necessary [26]. The Safety Manager will be responsible for updating the SMS with information about battery swapping as development and adoption grows throughout the aviation world. Each airport's Safety Manager would work closely with airport operations staff and private businesses in monitoring airport safety as it relates to battery swapping operations.

The FAA suggests including a safety risk assessment matrix to determine the level of severity and likelihood of hazards with the use of the formula established in the FAA SMS manual: Risk = Likelihood * Severity [27]. Reflecting the format of the SMS manual established by the FAA [27], the risk assessment matrix in Table 2 can be used for the proposed battery swap. The chart in Table 3 outlines potential hazards of the proposed battery swap and how the identified hazards rate in the matrix. According to a report released in early 2022 by the Airport Cooperative Research Program (ACRP), hazardous waste and leakage on-site or off-site at battery charging terminals can lead to contamination of surrounding soil, groundwater, or lead to other health issues, so the batteries must have a safe location to be stored, and they must be transported to and from the battery swap facility in a safe and efficient manner [8].

Power and electricity are major factors that are considered for airport operations. According to the ACRP report, on average at an airport, terminals utilize 60% of the electricity and the other 40% is utilized by airfields. For reference, the peak-power demand at the Pittsburgh International Airport is 14MW [8]. Although in this design the batteries could be charged off-site and would require less on-airport power than charging the batteries on-site, airports need to accommodate for the massive power requirement for eVTOLs and their batteries in instances where on-airport charging occurs. Electricity and power will be in high demand as

EVs and eVTOLs become more popular among the public and electric aircraft become the new normal for air travel.

Applying the matrix in Table 2 to the proposed battery swap, the biggest concern is malfunctions during the battery swap process. The results of installing the battery incorrectly can lead to various problems including injury, fire, or eVTOL failure. Possible mitigation methods include installing safety barriers between the workers and the dolly, and having at least three certified workers on-site, so that one worker can perform the swap and the other two workers can manage the safety of others. The transportation and containment of the batteries are medium risks based on the matrix. To mitigate these potential hazards, the batteries must be covered with weather resistant materials when being transported to and from the airport and the charging facility off-site. Any chemical waste that accumulates from battery leakage must be contained in proper containers.

Table 2. Safety/Risk Assessment Matrix for the Proposed Battery Swap

Severity / Likelihood	**Minimal 1**	**Minor 2**	**Major 3**	**Hazardous 4**	**Catastrophic 5**
Extremely Improbable 1	**1**	**2**	**3**	**4**	**5**
Remote 2	**2**	**4**	**6**	**8**	**10**
Probable 3	**3**	**6**	**9**	**12**	**15**
Frequent 4	**4**	**8**	**12**	**16**	**20**

Low Risk: 1 - 4
Medium Risk: 5 - 10
High Risk: 11 - 20

Table 3. Safety/Risk Assessment Summary

Hazards	Severity	Likelihood	Risk	Possible Solutions
Electric Dolly Malfunction	1	2	2	Have a back-up electric dolly on-hand
Electrical Battery Fire	2	1	2	Have an automated extinguishing system at the swapping station
Human Errors During Inspection	1	3	3	Provide regular training and maintenance
Power Outage	1	4	4	Install a back-up generator at the battery swap facility
Transporting Batteries in Severe Weather	3	3	9	Cover the batteries with weather resistant equipment while transferring batteries to and from the airport and the off-site charging facility
Chemical Leakage	4	2	8	Remove the battery and place the chemical waste in proper containers
Battery Swap Performance Malfunction	5	2	10	Install safety barriers between workers and the dolly; have at least two certified workers on-site while swapping batteries

8. Interactions with Industry Experts

8.1 Brian Smith

Regional Director of Aviation for New England at McFarland Johnson, Brian L. Smith, P.E., met with our team via Zoom on February 24, 2022. He helped our design by explaining the pros and cons of the electric battery exchange and informing us on how logistics of the battery exchange could look.

Mr. Smith first explained how the battery exchange would be beneficial from his point of view as a Regional Director of Aviation for an engineering firm that works at airports across New England. He mentioned the economic importance of the faster turn times, the flexibility of real estate, and cheaper utility prices if the batteries are charged off-site. Some airports, like John F. Kennedy Airport in New York, pay an appreciable amount for real estate and having many charging stations for aircraft would take up a significant amount of land and utility power. He then went into the disadvantages and described how some designs have the batteries incorporated into the actual structure of the aircraft, which would be implausible to swap, and the costs for having additional batteries lying around to be swapped. However, he affirmed that the design of batteries within eVTOL aircraft structure is subject to change depending on consumer demand.

Mr. Smith then went into how the logistics of the battery exchange could look. A one-size-fits-all approach to airports is not feasible as they differ in real estate and utility costs, available space, and policies. However, he mentioned any battery exchange would require the use of heavy machinery, space reserved for swapping, and labor. This information was especially helpful as it prompted some changes in the design team's construction of visuals of the battery swapping process.

Ultimately, Mr. Smith approved of the idea and validated how the revenues would outweigh the costs at some airports, but perhaps not others.

8.2 Noah Karberg

Nantucket Memorial Airport Assistant Airport Manager and Environment Coordinator, Noah Karberg, was interviewed by our team via Zoom on March 10, 2022. Nantucket Memorial Airport, specifically, was an airport of interest for the team because it is a perfect environment for eVTOL technology to be utilized as many of the flights are short flights from New England.

Mr. Karberg explained Nantucket's plans for adopting electric aviation in accordance with their strengths and limitations in terms of their ability to implement electric aircraft. Nantucket, specifically, anticipates utilization by eVTOL in the very near future. However, the airport is projected to have power and utility limitations. Nantucket is expecting to charge batteries on-site, and these utility costs are not inexpensive.

Currently, the island has two electrical cables with the design in place for a third. With a third electrical cable to supply power for increasing electric aviation needs, the rates/costs will go up 25-40%. However, he mentioned that charging batteries overnight during off peak hours with the battery swap system would allow these rates to be reduced.

Mr. Karberg also explained how the airport has identified lots, about .5-2 acres, that can be set aside for aircraft charging. He mentioned that this land would most likely not be suitable for photovoltaic generation, but it could be suitable for a battery bank/distribution hub.

A constraint of the battery exchange system that Mr. Karberg addressed is that no airport wants to be the first one to implement this system, so it would need a very strong proof of concept. Like Mr. Smith, Mr. Karberg believes that the swapping system could be suitable for some airports, but not for others.

8.3 Sam Hobbs

On March 22, 2022, our team met with a Beta Technologies team member, Sam Hobbs. Speaking with a Beta Technologies representative was an important goal for the team because Beta is a leader in manufacturing eVTOL.

Mr. Hobbs started off by stating that Beta Technologies has moved in the direction of recharging the batteries in the aircraft for the time being. However, he followed up by explaining how a hybrid approach in the near future is probable. This approach would most likely charge slightly drained batteries in the aircraft and swap batteries with little charge remaining.

He also provided some information on why Beta is not implementing a battery swap technique at the moment. The battery packs are very heavy and maintain overall stability by resting in the belly of the aircraft which makes it difficult to quickly get access to and replace the battery without proper machinery. The repetitive attachment and detachment of the battery of the aircraft could also cause some wear and tear on the aircraft.

Some possible benefits of B-Swap that Mr. Hobbs outlined come from the fact that the batteries would be trickle charged during off-peak hours. This would allow for the airline to avoid peak billing hours, use less energy to charge the battery, and increase battery longevity as compared to Beta’s current fast charging technique. Beta’s fast charging method fully recharges batteries in about 50 minutes, which would be more time consuming than a battery swap. Fast charging also degrades the cell more quickly than trickle charging, so the use of trickle charging in the battery swapping system would allow for longer battery life spans.

8.4 M. Stanley Whittingham

Binghamton University Professor M. Stanley Whittingham, a 2019 Nobel Prize laureate in chemistry for the development of lithium-ion batteries, met with our team on March 24, 2022, via Zoom. The team had desired to meet with Dr. Whittingham because eVTOL aircraft will be using lithium-ion batteries and he is a known expert in the field. Dr. Whittingham was able to give detailed explanations on the benefits of trickle charging versus fast charging and pros and cons of the battery swap concept.

To trickle charge a lithium-ion battery, the charge must come at a constant rate until it gets to some voltage standard, which is usually around 4.2V for eVTOL, then the battery could start to be slow charged. The many benefits of trickle charging that Dr. Whittingham outlined were longer battery life (longer voyages), less degradation of the battery over time, less time to wait to start charging after an aircraft has landed, and a lower cost to charge.

A con of the concept that Dr. Whittingham had outlined is the fact that some manufacturing companies are including the battery as part of the essential structure of the aircraft. However, he also believes that a model set in place with two batteries in an aircraft, one that is part of the structure and one that is swappable, could become the dominant method for these manufacturing companies in the future.

Another possible setback he outlined is the possibility of human error while swapping the battery packs. There is always the possibility of making improper connections, damaging the battery, and/or failing to adequately ensure safety. The battery swap should only be carried out by trained professionals.

9. Projected Impacts

9.1 Introduction

The projected impacts of battery swapping are monumental for the validity of electric aviation. Electric aircraft must increase the profits of operators in order to replace fuel-powered aircraft. Aircraft typically make the most money when downtime is minimized and airtime carrying passengers is maximized. Thus, aircraft profitability will increase if turnover time is reduced by replacing rapid charging with battery swapping. Likewise, batteries will need to be disposed less frequently if they are not always rapidly charged. Battery swapping has substantial commercial potential if it meets the FAA Goals and is feasible to be implemented.

9.2 FAA Goals

The primary goal of the FAA is to optimize safety and efficiency within America's air industry [28]. One of their strategic objectives is a systemic safety approach, which our system could help implement by standardizing the integration of electric aircraft into the industry. The FAA also aims to invest in infrastructure especially as the industry continues to advance [28]. The electrification of the industry will require a substantial amount of infrastructure, and each location will require its own special arrangement based on the resources available. Our swap station can be standardized, which makes it easier to implement across the country by minimizing the volume of infrastructure needed by a significant amount. Another FAA goal is to extend the life cycle of aircraft. Our charging system increases battery longevity and efficiency through around the clock slow charging that relieves pressure on the power grid and preserves battery life. The FAA strives to be as accountable as possible, including environmentally. Our proposal would eliminate more fossil fuel use and carbon emissions than the traditional fast charging idea, as slow charging would put less of a strain on the power grid and therefore demand less energy. With the lowered demand, a larger proportion of the energy could come from renewable sources rather than coal burning or similar methods. Power could be even more efficiently provided for the batteries due to the potential for off-site battery charging.

9.3 Commercial Potential

The commercial potential for our proposal is evident in the numerous revenue streams it provides. Our swapping station would likely be owned and operated by a private contractor but could be developed and run by an airport operator as an additional revenue source and service provided to users. This would not only be a potentially lucrative business and new industry but may also help in solving the labor shortage problem many airports face today. Private companies may be able to offer enticing compensation to employees and develop efficient business strategies. On top of this opportunity, existing aircraft operators may move to this idea due to the money-saving implications detailed in the following section, including the need for fewer aircraft and lower energy costs. Yet another commercial opportunity exists in the standardization of batteries as well as charging technology and adapters/connectors. Professor Whittingham predicted that many of the batteries to be used will be created by a handful of smaller companies, likely relying on some standards in a similar way that most jet engines are made by only a few companies today. Power generation companies could also benefit from the increased use and demand of electricity for the batteries.

9.4 Process for Implementation

To implement battery swapping, companies would first have to lease land from airports for the battery swapping station. Depending on space constraints and land costs, the same or a different private entity would either have to acquire additional land at the airport or off-site for the battery charging facility. The size of the facilities would be dependent on the size of the airport, and they would need to be fireproof to ensure no other buildings are damaged in the event of a fire. The buildings must also have the necessary fire equipment to contain a large electrical fire. Moreover, the battery swapping station would need to be easily accessible for electric aircraft to taxi into and support easy transportation for staff. After the facilities are built, batteries for all types of electric aircraft used at the airport would be purchased. The battery charging building would be highly organized, isolated, and have quick access to firefighting equipment and personnel. Additionally, the machines used to swap batteries would have to be purchased, and spaces to store the machinery would need to be created.

Technicians would need to undergo specific training and certification to swap batteries. A technician's ability to properly remove the battery without damage, securely mount a new one, and safely connect it electrically is paramount. Supervisors would also be trained and certified to check the swapping jobs of others and use computerized equipment to verify the integrity of the job. The computerized equipment would have to be developed such that it can detect a physical or electrical flaw in the battery swapping job in any aircraft. This combined supervisor and computer check would be done after every battery swap. After a technician's skill and safety is demonstrated, they would need to show that they can swap batteries as quickly as needed based on that airport's standard. Depending on the number of technicians and the number of electric aircraft operating at a given airport, technicians could either be trained to specialize in a certain type of electric aircraft or all electric aircraft.

Pilots would need to be briefed on how to taxi and park the aircraft at the battery swapping station. If the pilots are scheduled for a quick turnaround with the same aircraft, a sitting area would be necessary at the facility. Otherwise, a bus, monorail, or other form of transportation may be added. Furthermore, pilots would undergo training on how to diagnose and resolve a problem caused by a swapped battery while on the ground or in the air.

9.5 Affordability and Utility

The concept of swappable batteries within aircraft is truly a change in the scope of aviation and how fueling will work in the future. Through battery swapping, the utility of aircraft and batteries increases immeasurably. A concern that may be held by some is the need to own more batteries. It is true that by introducing the swapping of batteries, more batteries will need to be made available for swapping. However, this concern is addressed by the drastic increase in the usage of aircraft by reducing turnaround time and making them more cost effective, possibly decreasing the overall number of aircraft needed in a fleet to cover a flight schedule. The concept is incredibly beneficial in regard to the benefits in the battery life as well allowing for methods of charging to be used that prioritize maintaining the battery without worrying about the speed of charging. By allowing the batteries to be charged away from the aircraft, they can be charged at any time, at any place, in any desired manner. By choosing charging times, batteries can be charged outside of peak electricity cost hours. It also allows the batteries to be charged in other areas and save space needed by airports. This makes battery swapping an affordable and flexible option for charging.

There are other options as well that can be introduced with the implementation of battery swapping. It gives greater importance to the standardization of batteries. Standardizing batteries in aircraft would be revolutionary as the electric aviation industry is still new; now would be an ideal time to make changes that will set up the industry for greater future success. Standardization would allow for greater competition in battery development, speeding up battery development and reducing costs if taken on by private industries. It would allow battery swapping to become more widespread as well. While it seems unlikely that the whole industry may standardize around one battery, it is feasible that a few batteries could dominate the industry in the future. There are many other possibilities as well, such as the implementation of a hybrid aircraft with a swappable and non-swappable battery, which could introduce a backup power source and increase the energy efficiency of the aircraft.

9.6 Cost Analysis

The potential costs of our battery swapping method depend on various factors. Among these are the infrastructure costs and potential savings over the conventional model of rapid charging batteries in the aircraft. One large portion of costs is the cost of building the infrastructure needed to facilitate the battery swapping. However, it is impossible to calculate the costs of such facilities as there is so much variation between the needs and resources of every airport. Costs would be high but could be offset by the savings of not needing to build a power generation facility on the premises of the airport. Another high cost would be the laborers needed to carry out the swap process, but this would also vary depending on the scale of the operation and the location. Aircraft mechanics are in high demand, so this could raise costs higher. Machinery to do the swap would also need to be purchased but does not exist yet, so costs are not available. If the batteries were transported off-site, it would cost around $2.76 per mile with each truck carrying up to 80 batteries by weight [29]. In general, the infrastructure costs can be considered an investment into the airports, and much of the cost is mitigated by the savings of not having to build a power plant on site, longer battery life spans, quicker turnaround times, and less aircraft needed in operation. For some airports, like the Nantucket Memorial Airport, providing extra power requires extremely expensive measures such as additional undersea cables, which could increase electricity costs by up to 40%, per Nantucket Airport's Environmental Coordinator Noah Karberg.

For every ten aircraft used in the battery swapping method, 11 must be used in the rapid charge method to complete the same flight schedule [30]. Each aircraft costs $3 million to $5 million according to Sam Hobbs at Beta Technologies. Furthermore, in the battery swap method, 12 batteries would be needed instead of 11 for the rapid charging method. Battery swapping would then cost an additional $16,400 for the extra battery [30], but this cost is negligible compared to the cost of the additional aircraft.

Perhaps the biggest way battery swapping enables more revenue than rapid charging is faster turnaround times. Mr. Hobbs from Beta Technologies stated that the battery used in their eVTOL aircraft can be charged in 50 minutes. For a short-haul operation with cargo or passengers, the limiting factor for the turnaround time is this charging time. On the other hand, battery swapping can take as little as five minutes, which would significantly increase an aircraft's time in the air [31]. Therefore, battery swapping has the potential to generate several times more revenue than rapid charging batteries in aircraft, as displayed in Table 5.

Table 4: Operational Cost Analysis

	Battery Swapping	Rapid Charging
Expected Swap/Charge Time (Minutes)	5	50
In-Air Profit ($/flight)	83.52	83.52
Average Flight Length (Minutes)	9	9
Maximum Flights per Day	146	83
Maximum Profit per Day ($)	12193.92	6932.16

Joby Aviation, a manufacturer of eVTOL aircraft, indicates the profit in the air with four passengers is $83.52 per flight. Each flight averages 24 miles with a cruising speed of 165 mph [32]. This means the average flight is around nine minutes. The batteries on eVTOLs tend to last 150 miles [33], so this would mean about six flights could be completed before a charge is needed. The rapid charge method requires a 50-minute charge time per Beta's Sam Hobbs, while the swapping method could be completed in as little as five minutes. With the assumptions of each aircraft flying all day, with charges/swaps after every six flights, the swap method projects 146 flights per day, while the rapid charge method projects 83 flights per day. This amounts to an estimated maximum daily profit of $12,193 for the swap, and $6,932 for the charging.

Additionally, according to Professor Stanley Whittingham, batteries are heavier if they are designed to be fast charged. So, if an aircraft uses a battery designed for fast charging, it will have a lower capacity to carry cargo. However, if an aircraft uses a swappable battery, it will be able to carry more cargo and thus make more money for its operator. Thus, battery swapping has the financial edge over rapid charging both in terms of the necessary fleet size and the potential revenue from flights.

10. Summary and Conclusion

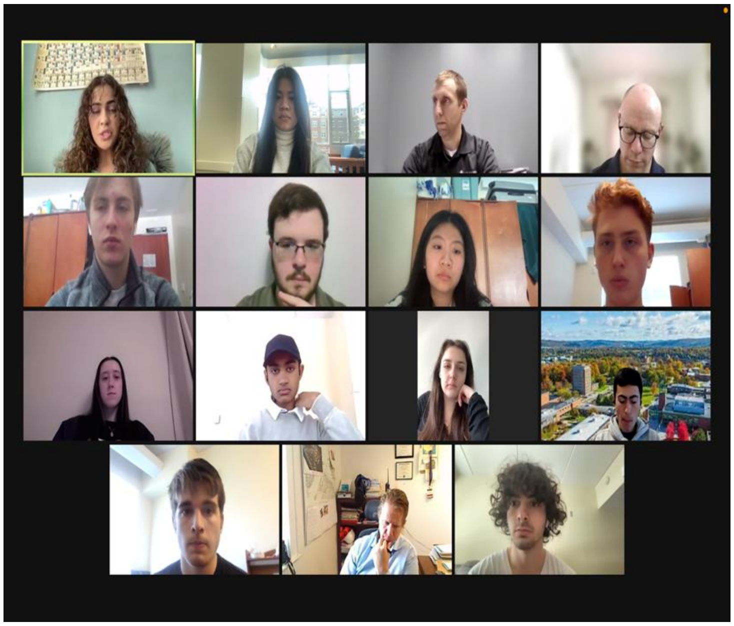
Through years of research on climate change, the aviation industry has been identified as a major contributor to global emissions. Considering the need to mitigate the effects of climate change; the FAA has identified, in *Destination 2025,* that it aims to reduce the carbon footprint of the industry through the pursuit of new, more sustainable technologies [1]. Simultaneously, the emergence of new technologies, specifically those related to the production of electric aircraft, has prompted the idea that a shift to a more environmentally friendly and energy efficient power source may be feasible.

Current efforts to incorporate these new technologies face challenges of both efficiency and infrastructure; charging on-site at locations such as aircraft parking spaces on the terminal apron and using traditional methods, such as plugging in a rechargeable battery, are time consuming and take up valuable resources and space at airports. Based on these drawbacks, our team searched to formulate a viable alternative. The first proposed solution involved the usage of a truck that would serve as a large battery itself and the aircraft would then utilize the truck as a power source, eliminating the need for large on-airport infrastructure. The second solution involved the creation of a battery swapping system which would place pre-charged batteries, charged either on-site or off-site, into the aircraft. Upon further research, it was decided that the latter was more promising, given that charging operations, which would likely not fully charge the battery each time, would degrade the battery's life over time and limit productivity due to lengthy charging times. Concerns our team had about swapping times, the safety of the procedure, infrastructure costs, and the environmental impact of battery disposal led to the contacting of industry experts to refine, adjust and solidify the concept.

This proposal discusses the creation of B-Swap, a battery swapping concept, to be implemented at airports across the globe. The operation would involve the removal of depleted batteries and the subsequent placement of fully charged batteries into electric aircraft through the usage of machinery such as electric dollies.

B-Swap would not only provide the foundations for the shift toward electric aircraft, but also toward a more sustainable and environmentally friendly industry. Through the reduction of turn times between flights and on-site power requirements, battery-swapping appears to be an

Figure 11. Team meets with Airport Operator Noah Karberg over Zoom



optimal solution for the future by maximizing efficiency and minimizing infrastructure costs. Investments in battery-swapping would also be adaptable to ever-changing technologies in electric aircraft such as the potential standardization of batteries or changes to the composition of batteries. Battery-swapping offers a solution to many of the issues that the aviation and overall transportation industries face in the pursuit of aircraft electrification.

Appendix A: List of Contacts

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Appendix B: Description of the University

About Binghamton University

Originally founded in 1946, Binghamton University (BU) is a top-ranked public research university, part of the State University of New York system, located in Vestal, New York

. Binghamton University is home to over 130 undergraduate programs as a part of its six academic colleges [34]. Binghamton University's commitment to public research has been recognized by the Carnegie Classification of Institutions of Higher Education who have rated Binghamton University as an R1 university with the distinction of "very high research activity", and its academic prowess has been awarded by US News with the ranking of 83rd in the nation [35].

Binghamton University Mission Statement and Values

Binghamton University commits itself to "collaborative transdisciplinary research, inspirational artistic endeavors and high-impact educational experiences within an environment that advances diversity, equity, and inclusion, international perspectives, and community engagement." In this quest we dedicate ourselves to being an internationally recognized institution "with the best undergraduate programs available at any public university" joined under campus values of unity, identity, and excellence [36].

Binghamton University Scholars Program Mission Statement and Values

The Binghamton Scholars Program commits itself to many missions. One such mission is intellectual curiosity where Scholars "Continually question, discover, and engage new knowledge.

Observe all sides and understand that there is always more to learn. Strive for mastery in one's discipline, while understanding the ways in which disciplines interact.” Another core mission is cultivating creativity, innovation, and the entrepreneurial spirit as we work to “Understand that new perspectives, performances, and ideas in business, engineering, the arts and sciences can better the world in which we live through innovation and excellence in the workplace; on the stage; in the studio, clinic, or laboratory; and beyond. Work[ing] to add to those new initiatives through research, academic efforts, and creative activities” [37].

Appendix C: Description of Non-University Partners

Beta Technologies

Founded in 2017 by entrepreneur Kyle Clark, Beta Technologies is an eVTOL focused aircraft manufacturer based out of Burlington, Vermont [38]. Beta's first targets for eVTOL usage "will be the transportation of natural and manufactured organs for transplant patients, and a US Air Force cargo and logistics mission", and the majority of the startup's funding has come from "United Therapeutics, a pharmaceutical and biotech firm based in Maryland and North Carolina" [39]. The company's current public prototype is the Alia-250C. "The result of 3 years of precise design and development" [40], Alia features a 50 ft. wingspan and "uses four propellers to lift like a drone and a fifth to fly forward like a plane. It's designed to carry six people or three pallets of cargo up to 250 miles, powered entirely by rechargeable electric batteries" [38].

McFarland Johnson Inc.

McFarland Johnson Inc., based out of Binghamton, New York, "is a 100% employee-owned multidisciplinary planning, design and construction administration firm" [41]. Their current Chief Executive Officer is James Festa, while the President and Chairman of the Board is Chad Nixon [41]. The firm states that its primary vision is to become a nationally recognized, innovative infrastructure consulting firm", while ensuring that "[e]very project [McFarland Johnson] undertake has unlimited potential for innovations that can add value for our clients, the users, our environment, our employee-owners and our communities" [41].

Nantucket Memorial Airport

Nantucket Memorial Airport, located in Nantucket, Massachusetts, is a community-owned airport that features "three asphalt runways – 6/24 (6,303ft, 1,921m), 12/30 (2,696ft, 822m) and 15/33 (4,000ft, 1,219m). There are around 450 aircraft operations at the airport a day, the majority of which are air taxi services (33 aircraft are based at the airport)" [42]. The airport was founded in the 1930s by "Leslie Holm, a farmer who lived in Nobadeer, who plowed over and smoothed his cornfields with the assistance of David Raub, who was a former test pilot that had moved in Nantucket. Together they managed to form the Nobadeer Flying Service and bought three small planes for charter and instruction" [43]. Currently, the most popular airlines to fly out of Nantucket Memorial are Cape Air/Nantucket Air, United Airlines, American Airlines and JetBlue Airways, and the airport boasts having 103,795 successful passenger enplanements so far this fiscal year (June 2021 to March 2022) [44].

Appendix E: Evaluation of the Educational Experience

<u>Student Questions and Responses</u>

1. Did the Airport Cooperative Research Program (ARCP) provide a meaningful learning experience for you? Why or why not?

Yes, the competition gave us a deeper insight into the aviation industry and further peaked our interests in issues within the industry. It also provided valuable opportunities to perform research in an environment simulating a STEM workplace.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

Our biggest challenge as a team was researching a concept that is new to the aviation industry with no previous knowledge or background in aviation. We overcame this challenge in multiple ways, including dividing workloads amongst four sub teams, interacting with professionals in the aviation and electric technology fields, and researching similar yet smaller scale battery swap implementations such as in the automotive industry.

3. Describe the process you or your team used for developing your hypothesis.

The process we went through as a team was researching potential ideas and then eliminating each potential idea one by one through discussion. After that, we took a vote based on the area of interest from the majority of the team.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Yes, interacting with industry professionals was extremely beneficial and meaningful. Each industry professional had different areas of expertise and offered a different perspective on our project, which provided us with an idea of whether or not our design was actually viable and realistic. Much of what we learned from our meetings we may not have been able to find from other sources, so to be able to have a live discussion with professionals proved very useful.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

This project helped us with reading various research papers and our ability to work in different teams within one large one. The whole setting of the team, talking to one another to discuss our progress within the week, was designed in a similar way to a workforce.

<u>Faculty Questions and Responses</u>

1. Describe the value of the educational experience for your student(s) participating in this competition submission.

The ACRP University Design Competition continues to provide a unique opportunity for students to learn about and formulate solutions to real problems. Such an opportunity is not typically included in the curriculum for freshmen (which make up the majority of our class) and the Competition provides this experience early in their college experience and enables many of them to work outside of their comfort zones to identify solutions to a problem in an industry where they have no previous experience. As part of the Competition, these students have learned to identify, research, and develop a concept to solve a specific problem. In addition, our students had to consider risks that may occur as a result of the implementation and consider the real-world implications that could occur as a result, including considering risks and avoidance opportunities. While electric aircraft are still in testing and not utilized in the fleet currently, the students have embraced the technology and have moved ahead on a concept that has little previous research in aviation. The students have had interactions with numerous industry personnel and in all instances, they have been commended for their forward-thinking ideas and their approach to the topic.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. All the students on the team are undergraduates and nearly all are in the second semester of their freshman year. As freshmen, nearly all these students have had limited opportunities to work in a team setting, as many introductory classes available to freshmen have much higher enrollment and fewer interactions with other students. The ACRP University Design Competition enabled us to bring a small group of students with varying academic interests, mostly in mechanical engineering together to work as teams on a project topic that many of them had never thought about or were even aware of prior to the start of the semester. The effort required constant communication and cooperation to ensure that submitted documents meet the course and competition requirements. As the course is offered in the spring semester, our students had to ensure that they were always able to meet timelines due to the submission deadlines imposed. Further, with modifications to the spring semester timelines due to the COVID-19 pandemic, our course meetings started a week after we had previously planned, while the competition deadline remained unchanged. These timelines required the teams to work cooperatively and adequately manage their time to meet specific deadlines set for members of the teams. All these elements are vital to the learning experience that will be useful for these students as they continue their education and move to professional fields.

3. What challenges did the students face and overcome?

There were several challenges for our students to overcome as they completed the proposal. The most dominant impact to date is the impact to classes associated with the COVID-19 pandemic. While our only significant impact was a one-week delay in the start of the semester, there were numerous circumstances where students were absent or participating remotely due to contracting COVID-19 or displaying symptoms. In the beginning of the semester when COVID-19 cases were peaking, which is a key point in our timeline as we are selecting projects, this led to some delays in the submissions of documents and required coordination to narrow down and select the ultimate project. This also led to a delay in identifying and scheduling industry experts for the students to coordinate with. While we were ultimately successful in scheduling time with four experts in the field, it ultimately occurred 2-3 weeks after it had initially been anticipated. Outside of the impacts of the COVID-19 pandemic, each student had limited to no knowledge of the aviation industry, which required additional time for them to learn about the key topics that relate to our proposal. We worked with our students early in the semester to ensure that they understood basic information concerning airports and airport facilities. Students were required to complete further research to confirm that they were competent in the areas necessary for their proposal. While a trip to a local airport to meet with airport executives and better understand the queuing process today would have been ideal, particularly with understanding how an aircraft fuels today and where electric charging could occur, it was infeasible in the current environment. However, the students substituted this experience with Zoom interviews of an airport engineer, airport executive, electric aircraft manufacturer, and an inventor of the lithium-ion battery. In addition, the type of research completed in this course is not typical for students at the beginning of their college careers and included concepts and requirements that may not have been covered in many of their previous courses or in high school. The ACRP University Design Competition maintains a strict deadline that requires the project leader to ensure that the submission schedule was followed. The project leader regularly checked in with each team to see what progress was made and set up portals for team members to share work efficiently.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes. We have used this format for over ten years, and plan to continue its use into the future. The format and structure of the Competition is ideal for this course at Binghamton University – State University of New York. Students who have previously completed this course regularly comment on the value of the experience after it has been completed, both in terms of understanding project management but also in their increased knowledge in one aspect of the aviation industry. This project allows students to not only work on a challenging academic exercise, but to work on one with real world applications that could potentially have an impact on the charging methods for electric aircraft as their development continues. This experience will be valuable as they continue through their academic career and move into the workforce.

5. Are there changes to the competition that you would suggest for future years?

The ACRP and FAA have ensured over multiple years that the suggested research topics remained relevant, and we recommend that the practice should continue. With the current academic environment and university calendar, including the second year of a delayed start to the spring semester, we appreciate the realignment of the due date in 2022 from late April to mid-May. However, it would be ideal if the ACRP Notice of Intent deadline were also extended later into February. This would better allow our team, as well as others, to submit our intent earlier in the process. Further, as the world continues to progress in sustainability and digital technology, ACRP should consider transitioning fully to digital submissions of the final report versus a submission of both digital and paper versions.

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