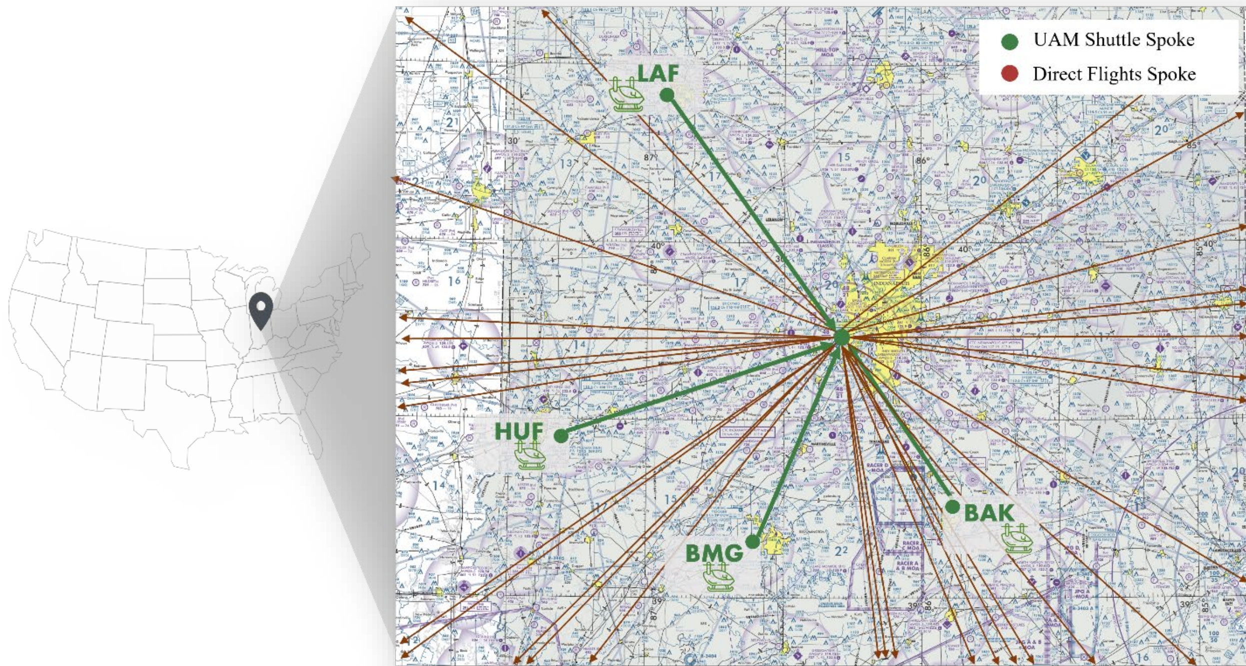
2022-2023 ACRP UNIVERSITY DESIGN COMPETITION

Advanced Air Mobility Shuttle from GA airports

(January 2023 – April 2023)



Note. The picture is reproduced using an *Aeronautical Chart* from the Indiana Department of Transportation, Office of Aviation (https://www.in.gov/indot/div/pubs/2018-2019_Aero_Chart.pdf), *America map* from Pixabay.com, and *UAM* image from Flaticon.com on April 28, 2023.

Design Challenge: Airport Management and Planning: Challenge A: Maximizing Airport Capacity

Number of Graduate Students:1

Number of Undergraduate Students:1

Team Members: Tanner Bowman, Junghye Lee

Advisor's Name: Mary E. Johnson, PhD

Name of University: Purdue University

Executive Summary

This design intends to create modern solutions for generating airport revenue for general aviation airports; as highlighted by the ACRP University Competition in the **Airport Management and Planning Challenge Category: A. Maximizing Airport Capability** (Airport Cooperative Research Program, 2022). In the wave of radical technology advancement and intensive discussion amongst stakeholders on advanced air mobility (AAM), the student team proposes a method of adoption to generate new revenue for general aviation (GA) airports, as well as to further accommodate underserved areas. This design is based on **using an sustainably powered Advanced Air Mobility to provide scheduled service between primary hub airports and GA airports.** The expected benefits of the implementation are:

- Create new revenue for GA airports from landing fees, green fuel sales such as electricity or hydrogen, and additional non-aeronautical revenue.
- Open more funding opportunities for GA airports, such as the Airport Improvement Program, Passenger Facility Charges, and Bonds.
- Provide air transportation to regions previously served or underserved.
- Reduce land-side congestion of busy hub airports by distributing ground access.
- Encourage the implementation of advanced technology within the aviation industry.
- Support industry shift toward environmentally sustainable aviation.
- Contribute to local economic growth through indirect and induced spending.
- Enable financially independent and self-sustaining airport management.

The design process used incorporates continuous feedback via double loops, for a more thorough and viable plan. The process included systems thinking, industry and expert discussion, a review of applicable literature, safety assessment, and a project impact analysis. **An initial cost-benefit analysis spans 10 years of the implementation period and yields a 2.92 ratio.**

Table of Contents

Problem Statement and Background

The Federal Aviation Administration includes approximately 3,300 airports in the National Plan of Integrated Airports Systems (NPIAS) that are open to the public, and eligible for the Airport Improvement Program (FAA, 2020a). Of these airports, 76% are classified as General Aviation (GA) (FAA, 2020a). A GA airport is considered a public-use airport that may have scheduled service but has fewer than 2,500 enplaned passengers per year (49 U.S.C §47102, 1994). In total, 1,240 rural GA airports provide a crucial service in connecting the greater aviation system to their local community (FAA, 2020).

General aviation produces 273,500 direct jobs nationally and contributes $128 billion to the US Gross Domestic Product (GDP) (PricewaterhouseCoopers, 2020). Despite their importance, it is common for GA airports to run at a loss and rely heavily on government subsidies due to the nature of the inferior revenue structure and lack of community connectedness (Kaps et al., 2001).

Meanwhile, larger airports suffer the inverse difficulty of GA airports. As traffic increases, ground access congestion rises because landside capacity remains constrained (typically by road and rail-based systems) (Janić, 2011). According to *ACRP Report 4: Ground Access to Major Airports by Public Transportation* (2008), automobiles serve as the primary method to and from airports in the U.S. Therefore, increased demand for travel has led to further congestion, resulting in bottlenecks in the flow of passengers, delays, and an increased risk of traffic accidents. Furthermore, increasing demand has had an impact on environmental externalities, such as greenhouse gas emissions and poor customer satisfaction (Sameh & Scavuzzi, 2018; Failla & Ventola, 2014). Typical solutions have been adding more lanes, expanding parking areas, and facilitating remote check-in to disperse passenger interarrival time.

Because of these factors, airports now seek an innovative method to meet ground access transport users' expectations of convenient accessibility in terms of time and distance, easy baggage handling, service regularity/reliability, and reasonable price as compared to alternative options that are also ecologically friendly (Janić, 2011).

The first White House summit on Advanced Air Mobility (AAM) was held on August 5, 2022, with more than seventy representatives across the nation from industry, policy makers, academia, the Federal Aviation Administration (FAA), and the National Aeronautics and Space Administration (NASA) (The White House, 2022). At the conference, Billy Nolen, Administrator of the FAA, shared the vision of AAM as a more inclusive mode of transportation that connects underserved communities with larger cities (FAA, 2022). Nevertheless, there are many bridges to cross before fully implementing the new system; technological development for the vehicle, integrating within the national airspace system, preparing infrastructure for new methods of propulsion, and policies to allow for AAM's safe employment.

Despite current obstacles, the implementation of an Advanced Air Mobility (AAM) shuttle service presents an opportunity for airports. Our team proposes a design that **addresses the problem of limited connectivity by providing a new transportation option that complements existing infrastructure and opens economic opportunities for both GA and primary airports.** By connecting these airports, they can attract new customers, thereby expanding their reach.

Summary of Literature Review

This section examines the literature on airport ground access transportation modes, the revenue structures of GA airports, and the technological and operational aspects of AAM to evaluate the feasibility of the design proposal. The review also considers the Small Aircraft Transportation System (SATS), and Hub and Spoke concept, drawing insights from their successes and shortcomings. Among the sources are ACRP publications, scholarly papers, the FAA, NASA, and aviation industry news resources.

Airport Ground Access

The public transportation market share for airports in the US ranges from 6 to 23%, depending on the airport size and the region's willingness to support such systems (NASEM, 2008). Airport managers are trying to increase this share due to environmental and operational concerns such as carbon emissions and road congestion related to personal cars (NASEM, 2008). *ACRP Report 4 Ground Access to Major Airports by Public Transportation* categorizes market targets into three categories: dense urban, exurban, and mid-suburban areas (NASEM, 2008). While boundaries are unclear, the mid-suburban market area is the largest, presenting challenges in deciding whether to start fixed and scheduled service due to 5 to 50 trip ends per square mile (NASEM, 2008). Decision-making behavior differs between long-distance travelers and regular commuters, highlighting the need to understand factors that influence mode choice, such as travel purpose and transit speeds, among others (NASEM, 2008).

Airport Revenue

Aeronautical and non-aeronautical revenues are the two primary revenue sources for airports. Aeronautical revenue includes income from aircraft-related activities such as landing fees, FBO and airline rental of hangars and offices, tie-down rents, fuel sales, and land use

(NASEM, 2019). Non-aeronautical revenue comes from retail and concession sales, parking, rental car operations, rent on non-terminal buildings and land, and in-airport advertising (NASEM, 2019). Airport managers have more discretion in determining the use of non-aeronautical revenue, while aeronautical revenue is typically more structured in its usage.

A survey by the ACRP found that fuel flowage fees serve as the main revenue source for 63% of GA airports (NASEM, 2009). While other significant sources of revenue include commercial land leases, hangar leases, agricultural leases, and landing/ramp fees (NASEM, 2009), which may vary by airport size and location (Kaps et al., 2001). GA airports typically have modest and fluctuating revenue, relying heavily on the FAA's Airport Improvement Program (AIP) for grants for capital investments (Kaps et al., 2001; NASEM, 2009). AIP grants are divided into Entitlement and Discretionary funds, with the the latter used for specific purposes, and the former being guaranteed funding distributed to each eligible airport; details are depicted in Table 1 (FAA, 2019).

Table 1

Airport Improvement Program Funds by category

Category		Notes
Entitlement	Passenger Entitlement	No. of passenger enplanement. Min.$1 mil., Max. $26 mil./airport
	Cargo Entitlement	Landed cargo weight
	Nonprimary Entitlement	Up to $150,000
	State Apportionment	20% of total grants available, less nonprimary entitlements
	Alaska Supplemental	Alaskan airports
	Small Airport Fund	Small hub (1/7), GA & Reliever (2/7), non-hub & non-primary commercial (4/7)
Discretionary	Noise and Environmental	≥ 35% of discretionary, not to exceed $300 million.
	Military Airport Program	≥ 4% of discretionary
	Reliever Set Aside	≥ 0.66% (2/3 of 1%) of total discretionary
	Remaining Discretionary	Capacity/ Safety/ Security/ Noise and/or pure discretionary

Note. Source from *AIP Handbook* by FAA, 2019, accessed March 8, 2023, (https://www.faa.gov/airports/aip/aip_handbook/media/AIP-Handbook-Order-5100-38D-Chg1.pdf)

GA airports can receive varying types of grants under the AIP, including nonprimary entitlement, small airport fund, state apportionment, variable discretionary, and cargo entitlement grants (FAA, 2019). GA airports without commercial service can receive a maximum annual nonprimary entitlement grant of $150,000, while those with commercial service and more than 10,000 enplanements in a year can receive up to $1,000,000 in grants (FAA, 2019). Commercial service airports with more than 2,500 enplanements per year are eligible to collect up to $4.50 per eligible passenger under the Passenger Facility Charges (PFC) Program. As passenger numbers increase, non-aeronautical revenue also grows as more people spend money in the airport, which contributes to a cycle of airport revenue growth.

Transition to Commercial Air Service Airport

Transitioning from a GA airport to a commercial service airport with over 2,500 annual enplanements is a daunting task, requiring significant resources and staff. *ACRP Research Report 16* recommends two essential steps that typically take 18-36 months: (1) acquiring the Part 139 Airport Operating Certificate and (2) implementing an appropriate security program (NASEM, 2019). This certification process entails preparing several plans and manuals, including an airport certification manual, emergency response plan, airport security plan, and snow and ice control plan (NASEM, 2019). To support these plans, airports may need to upgrade facilities and increase staffing levels for inspections, maintenance, and operation, as shown in Table 2.

Table 2

Facilities and equipment that may need to be improved

Airport Terminal and Apron	Landside
• Sterile, Holding, Baggage handling area • Security Identification Display Area • Screening Equipment	• Access roads • Parking, Dropoff areas • Commercial vehicle area
Airside	**Aircraft Rescue and Firefighting**
• Runway/taxiway and safety areas including Apron • Lighting/signage, Nav-aids, Obstruction clearing • Snow removal equipment and deicing agents	• Number of vehicles • Size of vehicles • Extinguishing agents

Note. Sources from *ACRP Report: Guidebook for Managing Small Airports* - Second Edition by NASEM, 2019, retrieved on March 8, 2023 (https://doi.org/10.17226/14275)

Advanced Air Mobility (AAM)

Definition

The FAA (n.d., para. 1) defines "Advanced Air Mobility (AAM) as an umbrella term encompassing highly automated, electric, air taxis, or electric Vertical Takeoff and Landing (eVTOL) aircraft." The term AAM encompasses both Urban Air Mobility (UAM) and Regional Air Mobility (RAM). According to *ACRP Research Report 243*, AAM technology has the potential to create an environmentally sustainable and equitable transportation system that provides essential and emergency services (NASEM, 2023).

Market forecast

The AAM market is expecting significant growth in the coming years, driven by advances in technology, increasing demand for urban transportation, and a focus on sustainability and efficiency in the transportation industry. The passenger AAM market in the United States is expected to expand to $57 billion dollars by 2035, with more than 16% of passengers currently using private and public transportation, anticipated to use AAM for commercial passenger mobility (Hussian & Silver, 2021). For the broader range, Morgan Stanley anticipates reaching $1.5 trillion dollars by 2040 (Jonas, 2019).

Autonomous transportation demand will be influenced by several factors, including service reliability, safety, travel time, and cost (Fu & Antoniou, 2019; Al Haddad et al., 2020). For instance, if the service is reliable and safe, it is likely to attract more users. The cost of autonomous transportation also plays a crucial role in determining its demand. According to Uber, the projected initial air taxi fares are $5.73 per passenger mile, with a long-term goal of reducing the cost to $0.44 per passenger mile (Johnson, 2019). On the other hand, Archer Aviation plans to charge between $3 and $4 per passenger mile (Weitering, 2023). It is worth noting that individuals who value their time and have high household incomes may be more likely to adopt this new service and be willing to pay extra for it (Fu & Antoniou, 2019).

Technological Aspects

There has been remarkable technical progress in the development of AAM vehicles in recent years, as AAM companies have been actively engaged in designing, testing, and certifying vehicles with regulatory agencies such as the FAA. As of February 2023, there have been no FAA certified AAM vehicles for passenger transportation. However, the FAA has issued airworthiness criteria for a special class of powered-lift aircraft under Part 21.17(b) to companies such as Joby Aviation and Archer Aviation (Warwick, 2023). The range of AAM vehicles varies depending on the design and technology, with Joby Aviation and Lilium's aircraft designed to have a range of up to 150 miles on a single charge, while Archer has a range of up to 60 miles (Kolos-Lakatos, 2021). The industry is advancing rapidly, with companies partnering across industries and with national institutes and the government to work towards certification and commercialization (NASA, 2021).

Airport Preparedness

ACRP Research Report 243: *Urban Air Mobility* highlights that scheduled intra-urban flights will serve as an initial passenger use case that will act as a bridge to air taxis in the long run (NASEM, 2023). The report also outlines key areas that must be addressed while developing an airport business case for UAM operations. These include securing funding, developing vertiports, establishing charging facilities and ground support equipment, improving cargo facilities, revising lease agreements, facilitating last-mile transportation, implementing weather systems, addressing land use, and exploring innovative solutions for larger airports that have already exceeded their airside capacity (NASEM, 2023).

Small Aircraft Transportation System (SATS)

First studied for its feasibility that later led to the concept of Personal Air Vehicles (PAVs) in 1999 (Malik, 2004), SATS was developed to fill a void in commercial travel options based at non-towered or radar airports, by utilizing general aviation-sized aircraft (TRB, 2002). Despite its namesake implying a primary goal of commercial transportation, NASA refined its study to focus on: high-volume operations at non-controlled and radar airports, reducing instrument weather minimums, and improving single-pilot ability in complex airspace (NASA, 2001).

The initial SATS concept was believed to appeal to business travelers, marketed as an "On demand service." Research revealed that 65% of business trips involve one of the 50 most populous cities in the country as both the trip's origin and destination; presenting a challenge of congested urban airspace in eventual integration (TRB, 2002). Further SATS research showed that 87% of leisure travelers' trips occurred between small-city and nonmetropolitan markets (TRB, 2002). However, leisure travelers tend to book their trips far in advance, prioritizing the cost of travel over schedule flexibility (TRB, 2002).

Hub and Spoke

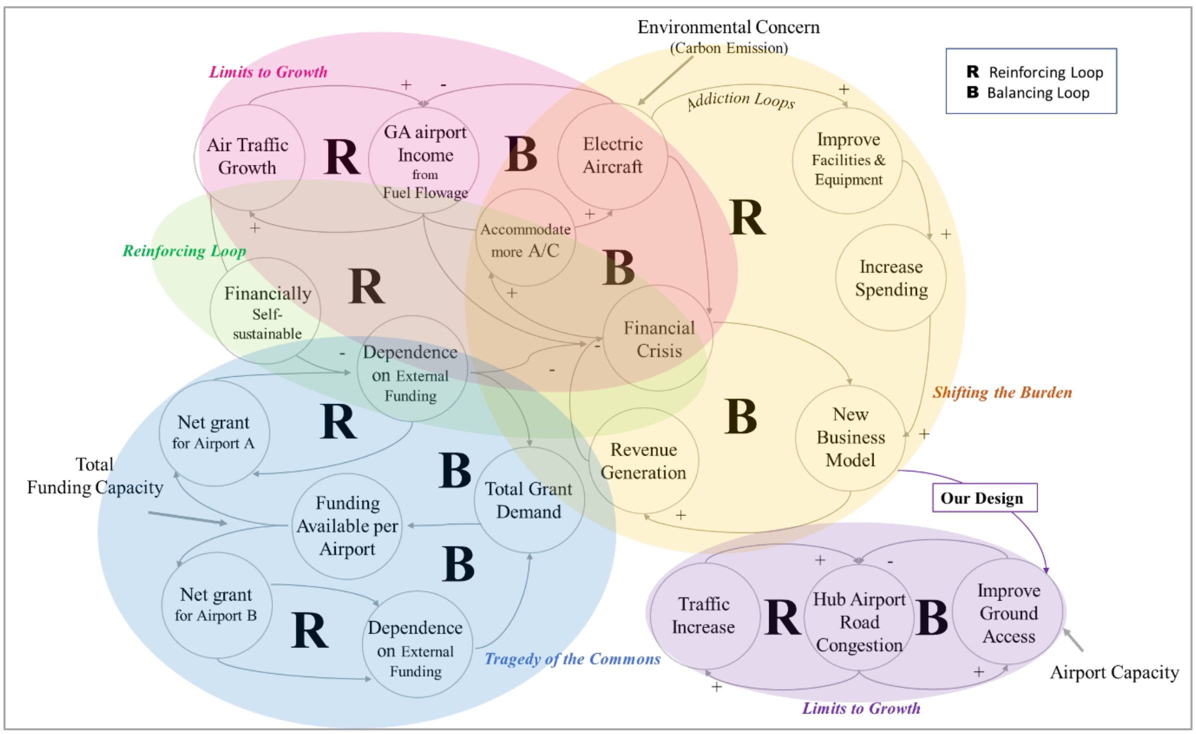
The "Hub and Spoke" model is used by airlines to efficiently route their aircraft to multiple destinations while minimizing the number of flights and legs (Cook & Goodwin, 2008). The model is comparable to a wheel's hub and spokes, with larger "hub" airports centrally, and smaller outlying airports connected by routes "spokes" to the hub (Cook & Goodwin, 2008). Passengers from smaller airports can fly to the hub and transfer to a flight to their desired destination, allowing for travel between any two cities in the network with only one stop (Zgodavová, Rozenberg, Szabo, 2018).

Problem Solving Approach

The team utilized systems engineering approach, following the guidelines suggested by ACRP, to determine the optimal design. The project commenced with an assessment of the current state and identification of challenges, as it is a crucial first step in systems engineering (Schreiner & Salado, 2019). To aid in this process, the team utilized the integrated 'Links and Loops' archetype, as proposed by Senge (1994), and depicted in Figure 1.

Figure 1

Identified GA financial concern related to the novel AAM technology



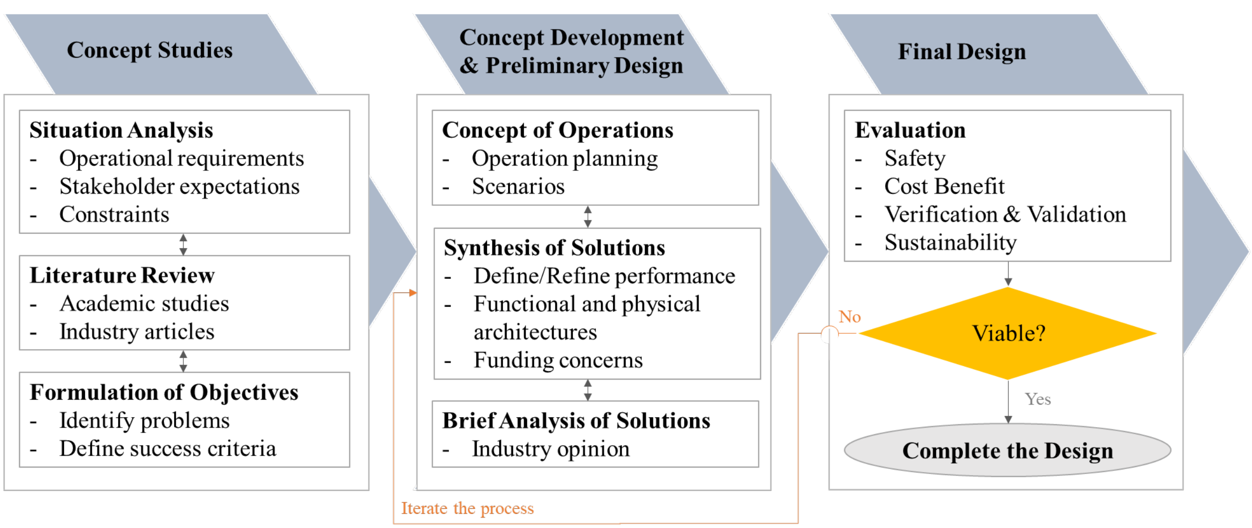
The primary revenue source for general aviation (GA) airports is typically the fuel flowage fee, which is closely tied to air traffic volume. However, the increasing use of electric aircraft in response to environmental concerns presents challenges for GA airports that rely heavily on fuel sales and lack the necessary infrastructure to support these new aircraft. In addition, transitioning to electric aircraft fuel sales requires costly facilities and equipment upgrades. To address these financial challenges, GA airports require a new business model that can generate additional revenue streams.

Meanwhile, hub airports serve as major transportation centers for commercial airlines and frequently experience ground access congestion. The current transportation options between GA airports and hub airports can be limited and time-consuming, particularly for travelers with tight schedules. Our design stems from the idea of offering a breakthrough for both GA and hub airports by providing new types of access transportation, thereby generating additional revenue.

The team conducted a thorough examination of the situation and determined the requirements and needs based on research papers and professional news articles. Once the success criteria were agreed upon, the team moved on to the preliminary design stage. During this stage to develop a more realistic design, the team considered operational, functional, and physical characteristics, as well as the available financial resources. Figure 2 illustrates the project life cycle of designing and executing a proposal in response to the identified issues and problems.

Figure 2

Project Life Cycle



During design development, the team sought guidance from a range of industry experts with experience in AAM implementation, such as airport directors, aviation consultants, and academic experts in aviation economics. Throughout industry engagement, the team identified disparities between stakeholder expectations and the current state. Key takeaways from speaking with experts are:

- Many GA airports that previously hosted commercial services still have sufficient demand for air service in their catchment area.
- Airport operators aim to increase air traffic to become financially independent.
- Passenger Facility Charges (PFCs) are flexible in their usage compared to government grants, which often have restrictions.
- Preparing vertipads on parking garage roofs might not be a viable option because of the structure's strength, and the potential impact on emergency response times in the event of an emergency such as thermal runaway.
- Airport bonds should be considered for capital funding as airports are often considered stable businesses that pay back.
- Lessons learned from SATS and helicopter transfer programs between airports in New York can provide valuable insights.

The team shifted the design focus towards alternative solutions after considering the challenges and insights gained from the initial round of interviews. Once the new focus was established, the team conducted a thorough assessment of the viability, quality, safety risk, cost-benefit, and sustainability of the design.

Technical Description

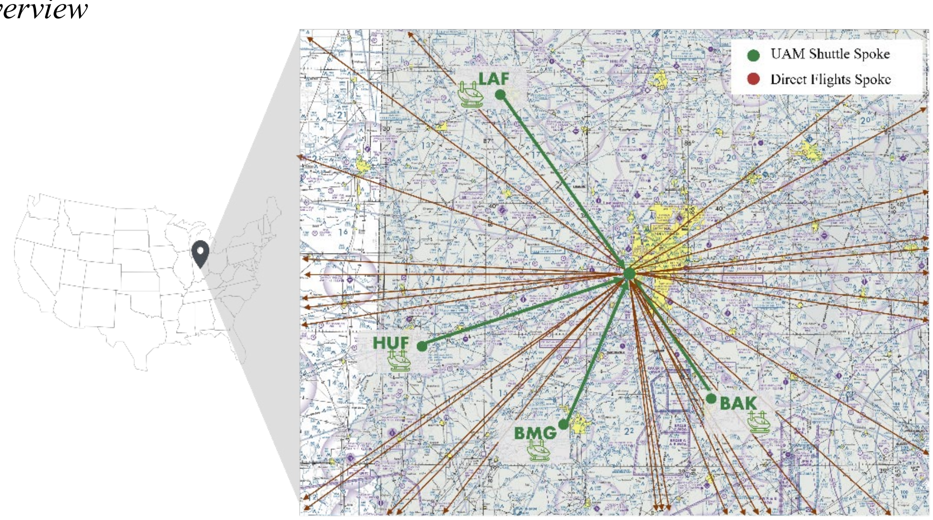
The design serves as **a roadmap for GA airports to implement scheduled AAM shuttle flights by leveraging existing infrastructure**. It utilizes a hub and spoke network, with **a primary hub airport at the center and GA airports acting as the small outlying spokes.** AAM craft can operate on a regular schedule between the GA airport and primary hub, following the principles of this network.

Market Opportunities and Examples

An optimal example for the proposed AAM design is the Greater Indianapolis market. Using Indianapolis International Airport (IND) as the Primary Airport in the model, potential "spoke" GA airports within a two-hour driving proximity include Columbus Municipal (BAK), Monroe County (BMG), Terre Haute Municipal (HUF) and Purdue University (LAF). Currently, IND offers 45 destinations, either year-round or seasonal (IAA, 2023). By connecting these GA airports to IND, travelers can enjoy a faster and more convenient route to their final destination, potentially increasing demand for air travel.

Figure 3

Concept Overview



Note. The picture is reproduced using *Aeronautical Chart* from Indiana Department of Transportation, Office of Aviation (https://www.in.gov/indot/div/pubs/2018-2019_Aero_Chart.pdf), *America map* from Pixabay.com, and *UAM image* from Flaticon.com on April 28, 2023

In a sit down with an industry expert, the team discovered that LAF, HUF, and BMG hosted commercial air service in past years, but saw their providers pull-out due to excessive costs in a low willingness to pay market; despite possessing consistent demand for regional air travel. These airports **all host similar demographics of clientele serving college towns, industrial/large organizational business, and are located 1-2 hours' drive away from the IND primary hub airport.** The team also learned in an interview of a recent market demand research study; demonstrating that within a 45-minute drive of LAF, on average 1.1 million airplane tickets are purchased per year. The preferred airport demographics for the AAM design criteria are summarized in Table 4.

Table 4

Preferred Airport Demographics Criteria

Preferred Airport Demographics for Design Integration	Notes
● College Town	*Campus Size of ~10,000+*
● Heavy Industry/Commercial Industry Presence	*Fortune 500 Industry or Affiliated Enterprises*
● Municipal Population	*Community Population ~50,000+*
● 1-2 Hrs Drive to a Primary Hub	*Small-Medium Primary Hub*
● Previous Commercial Service	*Might have hold Part 139 Airport Certificate*

In times of high migration, GA airports fitting and serving the previously described demographics can directly benefit from the implementation of this design due to high demand. **Utilizing AAM aircraft and adopting their integration will allow airlines and airports to reopen previously closed markets, as the operation of AAM craft can lower previously high operational costs; and allow rural GA airports to receive commercial enplanements once again.** This design will also fulfill GA airport's Mission to cultivate outside relationships within the community, by engaging customers not normally served by GA airports.

One additional eventual opportunity to expand AAM enplanements at GA airports (upon further technological and network development) includes the opening of routes conducted between GA airports and urban points of interest. These markets allow for direct transportation to metropolitan areas, without the requirement of ground transportation from a primary hub to the point of interest. Example: LAF (Purdue's West Lafayette Campus) to Purdue's Indianapolis campus, several miles east of IND. Or BMG (Indiana University's Campus) to Indiana University's Indianapolis Campus, several miles east of IND.

Direct Revenue Opportunities

While each airport's Master Plan, regional demographics, and airfield layout are unique, our AAM integration design has the potential to create several revenue streams for small GA airports. In optimal circumstances, these **revenue streams may include passenger parking fees, green energy fuel fees, airside and landside facility usage fees, passenger facility charges, and in-airport advertising sales.**

The AAM integration design enables small GA airports to attract more passengers and tenants, thereby increasing the number of potential customers for the above-mentioned services. Additionally, the design facilitates efficient and environmentally sustainable airport operations, which may attract airlines and other aviation-related businesses that prioritize sustainability.

In addition, implementing the proposed AAM integration design can also create opportunities to secure **additional capital funding from stakeholders such as the Airport Improvement Program (AIP), Passenger Facility Charges (PFCs), and bonds.**

Airport Improvement Program

AIP serves as a substantial source of annual and capital improvement funds for eligible airports of the National Plan of Integrated Airport Systems (NPIAS). AIP grants can be classified as Discretionary or Entitlement, with Discretionary Grants disbursed for specific proposed projects and Entitlement Grants guaranteed based on qualifications such as annual commercial enplanements. If the total grants available for the year exceed $3.2 billion, the Nonprimary Entitlement Grant provides a base entitlement grant of $150,000. Once a GA airport reaches the threshold of 10,000+ passengers in a calendar year, **the Nonprimary Entitlement Grant increases from the base $150,000 to $1,000,000** (FAA, 2019). Additionally, once an airport reaches 10,000+ enplanements and is classified as **a Primary Airport**, it becomes eligible for the Primary Entitlement Grant, which offers more funding opportunities. Grant amounts can range from **a minimum of $1,000,000 up to $22,000,000**, as per FAA (2019) regulations.

The team suggests a scheduled AAM shuttle service with a minimum of 10 departures from GA airports. This is because scheduling 10 daily departures with a vehicle that has a maximum capacity of 4 passengers with an average load factor of 80% can enable an airport to exceed 10,000 enplanements per year, as demonstrated in Table 5.

Table 5

Average AAM Departures/Day	Passenger Capacity/Vehicle	Average Load Factor/AAM	Average Enplanements/Day	Annual Enplanements
10	4	80%	32	11,680 (Over 10,000)

If a GA airport surpasses 10,000 annual enplanements in a given calendar year, it becomes a primary airport in the subsequent fiscal year and can qualify for the Passenger Entitlement Grant, which is the second grant opportunity available through AIP. This grant allows the airport to collect up to $15.60 per passenger (FAA, 2019.)

Passenger Facility Charges

Commercial service airports, defined as public-use airports enplaning 2,500 or more passengers per year, may request authority from the FAA to impose a Passenger Facility Charge (PFC) up to $4.50 on revenue passengers (FAA, 2022). The collected PFC fees are used to fund FAA-approved projects that improve safety, security, capacity, noise reduction, or air carrier competition (FAA, 2022). An airport with 10,000+ enplanements per year collecting the maximum $4.50 per enplanement, can generate an additional $45,000+/year. However, before airports can collect PFCs, they must obtain authorization from the FAA for the fund's usage on specific projects. The FAA approves a majority of PFC applications, with only a few exceptions that occurred in the beginning of the program (Bilotkach, 2018).

Airport Municipal Bond

GA airports are often limited in the size of the bonds they can issue due to their inability to pay back larger bond principals. However, GA airports can leverage additional revenue generated from scheduled AAM services, such as PFCs, to cover debt service and financing costs associated with AAM service (FAA, 2022). Implementing this design allows GA airports to sell larger revenue bonds and industrial development revenue bonds to finance revenue-generating investments or essential facility upgrades (NASEM, 2019). This provides additional funding options, allowing them to invest in upgraded or new facilities such as terminals, hangars, and fueling facilities. Bonds can also be used to acquire operational or maintenance equipment such as ARFF, snowplows, service trucks, and improve airport ground infrastructure like runways, taxiways, and lighting.

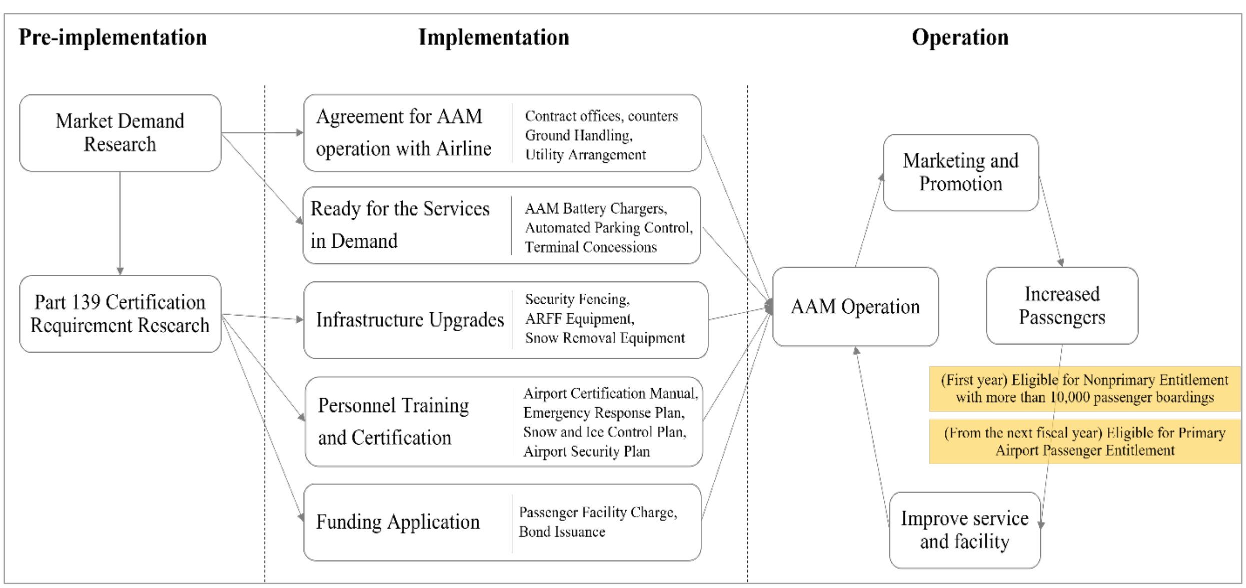
Prerequisites to Full Design Integration

AAM manufacturers maintain that their aircraft will enter service in or around 2025. This will allow GA airports looking to adopt this design the opportunity of time to make a series of facility investments to receive and adopt a Part 139 Operating Certificate to prepare for the adoption of AAM flights and commercial enplanements.

Taking an average 18-36 months to acquire a Part 139 Airport Operating Certificate, *ACRP Research Report 16* highlights the required steps and programs to move forward (NASEM, 2019). In preparation for the new passenger and aircraft traffic, airports will need to align themselves for Part 139 Certification by developing an airport certification manual, emergency plan, safety plan, and security plan. Subsequently, airports will need to upgrade their facilities to enforce the new plans, upgrading barbed wire fencing, required ARFF equipment and training, designated TSA security areas, and ice/snow removal equipment (NASEM, 2019). Figure 3 demonstrates the steps airports should take.

Figure 3

Airport Steps to integrate AAM Operation



It is important to understand the application and approval processes for PFC and Bonds issuance. To qualify for PFC funding, airports must go through an application and approval process with the FAA. Non-hub airports have a simplified process than that of hub airports. First, non-hub airports must select a project that meets eligibility criteria outlined in FAR Part 158. Then, they must write their own unique PFC application, coordinate with the FAA, and hold an airline consultation meeting. After meeting with the airlines, the airport sponsor submits the application to the FAA for review. Once the FAA provides comments and negotiations, the airport revises the application and resubmits it. After final FAA approval, the airport must notify the airlines to begin PFC collections and disburse payment every quarter (NASEM, 2019).

To issue bonds, GA airports commonly utilize municipal bonds, which are issued exclusively by public organizations and governments such as airports. As a result, an external underwriter is required to bring the bond to market. To simplify the process of issuing a municipal bond, it is recommended that GA airports hire a municipal airport financial advisor. These advisors help to develop the bond terms and conditions and work with the underwriter to ensure successful bond issuance (MSRB, 2018).

Differentiation from NASA's SATS Program

The proposed design has a distinct objective from NASA's SATS Program: to increase passenger enplanements and GA airport funds for long-term business sustainability. Unlike SATS, which prioritized safety technology and viewed transportation network development as a byproduct, this design focuses on commercial viability.

A key difference between the proposed design and SATS is the use of AAM aircraft specifically designed for commercial carriers. In contrast, SATS relied on non-commercialized, privately-owned civilian single and multi-engine aircraft. The proposed network would operate like full-sized regional and commuter airlines based on calculated demand; allowing pilots, carriers, and passengers to plan and operate accordingly. For successful implementation, the network would need to be adopted in coordination with airlines' operations.

Aircraft Type

This design seeks to incorporate a new breed of aircraft that can run on sustainable power sources like electric or hydrogen. Modern examples of these aircraft are in continued development but are being spearheaded by companies such as Archer Aviation, Joby Aviation, and H2FLY. While many AAM aircraft are capable of Vertical Takeoff and Landings (VTOL), most AAM are also capable of standard takeoff and landings. This analog feature saves airports crucial dollars and airfield space by not having to invest in a designated VTOL area or helipad; and opens the door for GA airports to accept their commercial service with ease.

Current designs of AAM aircraft vary in size, capacity, power plants, and degree of automation. For example, Archer’s aircraft can carry four passengers, up to 100 miles at speeds up to 150 MPH (Archer, 2023). Joby's aircraft can also carry four passengers, but with a range of 150 miles at up to 200 MPH (Joby, 2023). Meanwhile, H2FLY’s proposed air taxi model has a capacity of 6, with an estimated range of 500 kilometers (310 mi) (H2FLY, n.d). The AAM shuttle design targets the middle market with trip ends ranging from 5 to 50, a segment that is challenging to serve with previous fixed - high density public transportation (NASEM, 2008). Since medium-density modes are recommended for this market (NASEM, 2008), AAM aircraft capable of accommodating 4-6 passengers would provide an efficient and reliable mode of transportation. Future AAM aircraft are expected to carry up to 100 passengers, and this design leverages current AAM models as the foundation for operations, with the anticipation that upcoming regional-sized AAM models will enable scalability of operations.

Safety Risk Assessment

Prioritizing safety is of utmost importance in the aviation industry, especially when introducing new technology or operations. To ensure safety, the FAA mandates that all airports perform safety risk assessments as part of their Safety Management System (SMS) (FAA AC 150/5200-37). The primary objective of this process is to proactively identify potential hazards and determine appropriate measures to mitigate them to an acceptable level. The assessment procedure involves creating a system description and risk identification. Further allowing for the risk's analysis, assessment, and control. The team also utilized the Failure Mode and Effects Analysis (FMEA) method to identify risks/hazards, which are outlined in Table 6.

Table 6

Failure Modes and Effects Design Analysis

Potential Failure Mode	Potential Effects of Failure	Potential Causes of Failure
A. Thermal Runaway	Lost airport revenue, destruction to airside property, potential injury to personnel and passengers	Extreme air temperature, excessive battery temperature, and overcharging
B. Operational Vortices	Damage to aircraft, persons, or other vehicles	VTOL Operations in confined spaces
C. Separation from other aircraft	Collision, Aircraft Destruction, Passenger/crew/civilian injury, Damage to Ground Objects/Structures	Communication Breakdown, Lack of Situational Awareness, Air Traffic Control (ATC)
D. Icing/Cold Weather operations	Stall of an aircraft, destruction to ground property and airframe, personal injury to personnel and passengers	Icing/Cold weather, Precipitation, electrical heat failure
E. Operational Control Error by A/P (Autopilot) or Manual Pilot	Lost airport revenue, damage to aircraft, ground equipment, injury to passengers, crew, or civilians, etc.	Incorrect A/P Input, Spatial Disorientation, Lack of Situational Awareness
F. Passenger fall or injury during loading and unloading	Passenger Injury, Legal Ramifications	Lack of Stepstool or Handrail, Protruding/Sharp Surfaces/Edges

In accordance with the definitions of severity and likelihood for hazard outcomes proposed in Advisory Circular 150/5200-37A on Safety Management Systems for Airports, the initial risk levels can be evaluated using the safety risk matrix as plotted in Figure 4 (FAA, 2023). The matrix utilizes a scale ranging from 1 to 5, where 5 indicates a catastrophic event and 1 represents a minimal risk. The letters 1 through 5 are used to indicate the probability of an event, with 5 signifying the highest likelihood and 1 indicating the lowest probability.

Figure 4

Safety Risk Matrix

High Risk : 12 ~ 25		Severity				
Medium Risk : 6 ~ 10		Minimal 1	Minor 2	Major 3	Hazardous 4	Catastrophic 5
Low Risk : 1 ~ 5						
Likelihood	Frequent 5					
	Probable 4			B		
	Remote 3				A C	
	Extremely Remote 2			F	E	D
	Extremely Improbable 1					

The FAA defines Safety as being an acceptable level, and initially identified risks in the safety risk assessment should be mitigated and transferred through a systematic design approach, the involvement of operation experts, and ongoing training (Virginia Space Grant Consortium, 2016). Once mitigation measures are applied, the severity and likelihood of risks can be reduced and transferred as illustrated in Table 7.

Table 7

Residual Risks after the Mitigation Measurements

Hazards	Severity (1~5)	Likelihood (1~5)	Initial Risk	Mitigation	Residual Risk
A. Thermal Runaway	4	3	High Risk 12	·Sensors to prevent overcharging and detect extreme temperature · Equipment and training for fire	Moderate Risk 9
B. Operational Vortices	3	4	High Risk 12	·Separation protocol ·Advanced sensing and tracking tech	Moderate Risk 9
C. Separation from other aircraft	4	3	High Risk 12	· Dedicated zone for AAM operation · Collision Avoidance System	Moderate Risk 9
D. Icing/Cold weather operations	5	2	High Risk 10	· Deicing facilities · Improve performance in icing cond.	Moderate Risk 8
E. Operational Control Error by A/P (Autopilot) or Manual Pilot	4	2	Moderate Risk 8	·Communication and education among stakeholders involved ·Emergency preparedness	Low Risk 3
F. Passenger fall or injury during loading and unloading	4	2	Moderate Risk 8	·Well-lit, properly marked, and free from obstacles or any hazards ·Education of ground staff	Low Risk 4

According to Shahid and Agelin-Chaab (2022), lithium-ion batteries are expected to remain the primary battery composition used in electric vehicles due to their technical efficiency and ongoing development trends. However, the use of lithium-ion batteries also comes with safety concerns, particularly related to thermal runaway. Thermal runaway can occur due to factors such as overcharging and extreme temperatures and can pose a significant safety risk during battery charging processes at airports. Efforts are being made to develop effective methods to prevent battery fires and manage thermal events, while also avoiding external short circuits. Although these methods are still in development and require further research to ensure their effectiveness. At the airport level, it is important to be prepared for ARFF (Aircraft Rescue and Firefighting) equipped and trained to handle battery fires, which must be treated differently from traditional gas explosions. Additionally, airports can take preventative measures by installing charging stations with overcharging sensors and providing shade to prevent excessive temperatures on the apron.

Operational vortices can also be a hazard associated with the vertical takeoff and landing (VTOL) operation of AAM vehicles. When a VTOL aircraft takes off or lands, it generates powerful vortices or wake turbulence, which are rotating masses of air that trail behind the aircraft. These vortices can be hazardous to other aircraft, particularly smaller ones, that are in close proximity to the VTOL aircraft. To mitigate this hazard, operational protocols will need to be developed to ensure that AAM vehicles maintain a safe distance from other aircraft during takeoff and landing operations. In addition, the FAA can establish aircraft separation distance requirements for AAM, as they do for traditional runway operations for larger aircraft.

One of the main hazards is the potential for collision with obstacles or other aircraft during takeoff and landing operations. Additionally, the proximity of multiple AAM vehicles operating in the same airspace could also increase the risk of mid-air collisions. To mitigate these hazards, appropriate risk management strategies will need to be put in place. This may include developing dedicated landing pads and takeoff zones for AAM operations and advanced air traffic management systems to ensure safe and efficient operations. Also, technological advancements in areas such as collision avoidance systems will help ensure the safety and sustainability of AAM operations.

Operating an aircraft in a cold climate region presents unique challenges, including the risk of icing-induced stalls. While both propeller aircraft and jet engine aircraft can be affected by icing, propeller aircraft may be more vulnerable to ice accumulation due to their wing shape and lower airspeed. This susceptibility to icing was tragically highlighted by the 1994 crash of American Eagle Flight 4184, which led to increased focus on anti-icing and de-icing procedures for aircraft (American Eagle Flight 4184, n.d.). It is worth noting that electric vertical takeoff and landing (eVTOL) aircraft will likely be propeller-driven due to their need for vertical takeoff and landing capabilities. For airport operators in cold climate regions, providing adequate deicing facilities is crucial for ensuring safe aircraft operations. At the same time, aircraft manufacturers are also working to improve the performance and airworthiness of their aircraft in icing conditions.

Control errors by autopilot or manual pilot pose significant hazards and risks in AAM operations. However, airport operators can take steps to mitigate these hazards. Firstly, close collaboration with AAM operators and regulatory agencies is essential to develop and implement standardized procedures for AAM operations. This includes establishing clear lines of communication and coordination between all stakeholders involved. Secondly, airport operators can provide training and education to their staff and stakeholders on potential hazards and risks associated with AAM operations and the best practices to mitigate these risks. Finally, being prepared for worst-case scenarios is also important, including fast dispatch of emergency services and hospital coordination to handle the initial golden time.

There are also risks of passenger injury during loading and unloading of AAM vehicles. To mitigate these risks, airport operators can ensure that the loading and unloading areas are well-lit, properly marked, and free from any obstacles or hazards. Additionally, proper training can be provided to ground staff responsible for handling passenger luggage to prevent mishandling and accidents.

Projected Impacts of the Design

The subsequent segment is bifurcated into two sections, both aimed at evaluating the financial feasibility and potential sustainability of implementing the proposed design. This will be accomplished through the utilization of a benefit-cost analysis and a sustainability assessment.

Benefit-Cost Analysis

Benefit-Cost analysis is a decision-making tool for managers that aims to compare the costs and benefits associated with a given project to determine its overall value. The primary purpose of this analytical approach is to enable decision-makers to assess the potential costs and benefits of a particular course of action and subsequently make informed choices that optimize benefits while minimizing costs. Particularly in the context of the present design proposal, decision-makers can evaluate the commercial viability of the project by carefully weighing the costs against the benefits. The Airport Cooperative Research Program (ACRP) recommends that cost/benefit analyses should incorporate considerations of practicality, realism, affordability, utility, and comprehensiveness (Virginia Space Grant Consortium, 2021).

To furnish a more concrete financial appraisal, the team intends to adopt a hypothetical scenario involving an airport currently classified as a General Aviation (GA) airport that aspires to transition to a primary airport. The airport's confidence stems from their knowledge of the catchment area, which can accommodate over 10,000 passengers annually, and is situated 50 to 60 miles away from a medium-sized hub airport with no public transportation options except personal cars. The team's approach towards the analysis is to exercise caution and incorporate conservative assumptions. The analysis will span over a period of ten years to showcase how swiftly an airport can recuperate their investments.

Benefits

The ACRP guidelines list benefits of a design's implementation as an outcome leading to a directly positive financial return, or indirect financial return through the prevention of operational/environmental accidents. The benefits highlighted stand as positive returns for the airport, either as direct revenue through airside operations, landside operations, and AIP Capital Improvement Grants along with PFCs. Table 8 assumes an airport that has an annual enplanement of 10,000 and operates 10 daily departures.

Table 8

Benefits of the project for 1 year

Direct Income	Rate	1 Year's Revenue	Remarks
Parking	$5/car	$50,000	$10 per car * 10,000 passenger * 50% (Assumes 50% passengers use car to access)
Landing	$1.83/1000lbs	$26,718	$1.83/1000lbs * 4,000lbs * 10 departures/day * 365 (KSA, 2021)
Facility Rent	$16/sqft.	$364,800	Avg. office lease rate in West Lafayette: $16.02 (Loopnet, n.d.) $16/sqft * 1,900sqft(TSA 1,500sqft., Concession 400sqft) * 12months
Concession fee	10%	$11,400	Average food & beverage sales productivity in Non-Hub airport $285/sq ft * 400sq ft*10% (NASEM, 2011)
Green Fuel Sales	N/A	$100,000	Estimated Income from selling eco-friendly fuels such as electricity
PFCs	$4.5/pax.	$45,000	10,000 passengers
AIP	$774,200/year	$774,200	Amount shown is difference between 10-year average funding in Table 9 and base nonprimary entitlement of $150,000/year: $924,200-$150,000
Subtotal benefit		$1,372,118	**10-year revenue: $13,721,180**

Note. These figures are estimates based upon research and interviews with industry experts and are not adjusted for inflation. Method was adapted from the ACRP Resource Video on *Guidance for preparing Benefit/Cost Analyses* (Byers, 2016)

The parking fee is calculated based on Purdue University's 24-hour rate of $10, which starts at $3 per hour and increases by $1 for every additional hour, up to a maximum of $10. As for the landing fee, it is currently not charged to small aircraft by LAF but may be added once scheduled commercial operations begin. An average rate of $1.83 per 1000lbs, based on the average rate of GA airports, as reported by KSA (2021), is applied to 4,000lbs of the Joby vehicle for 10 daily departures. The terminal lease rates are applied based on market average in the region. Lastly, the AIP funds are calculated based on the annual average amount over a 10-year period, and a detailed breakdown of AIP grants for each year is presented in Table 9.

Table 9

AIP Fund Estimate for 10 years

Year	Activity	Airport Status	Funding & Amount
0	Current operation without AAM. Apply for collecting PFC.	GA airport	·Nonprimary Entitlement $150,000
1	Achieve 10,000+ enplanements at the end of the first calendar year with AAM operation	GA airport	·Nonprimary Entitlement $150,000
2	Start the fiscal year as a primary airport from October 1	GA → Primary airport	·Nonprimary Entitlement $1,000,000
3~10	Primary airport criteria applied with 10,000 enplanements per year	Primary airport	·Passenger Entitlement $1,000,000 + ($15.60/ pax. * 10,000)
10-year sum (year 1~10)			**$9,242,000**

Costs

According to the guidelines set forth by ACRP, the analysis of costs is separated into two main phases: research and development (R&D) and implementation. The R&D phase is further broken down into two parts, namely alpha and beta phases, which encompass the expenses involved in developing the concept of the design and customizing the implementation roadmap for individual airports, respectively. To estimate the cost of the initial development period, Alpha

R&D, we calculated the team's time spent on the ACRP design competition, which totaled 120 hours (an average of 10 hours per week over a 12-week period). In addition, we factored in the cost of faculty advisor involvement and any potential miscellaneous fees as shown in Table 10. This cost is a one-time expense that can be distributed among multiple airports if the design is widely adopted.

Table 10

Cost for Research and Development [Alpha] phase

Item	Rate	Qty.	Total	Remarks
Labor - University Design Competition				
Students Efforts	$30/hr	240	$7,200	10 hours/week * 2 students * 12 weeks; Purdue University student rate ($30)
Faculty Advisor	$120/hr	24	$2,880	2 hours/week * 1 advisor * 12 weeks; Purdue University student rate ($120)
Expenses				
Miscellaneous	$1,000	Lump sum	$1,000	Travel, Office supplies, etc.
Subtotal			**$11,080**	*** One-time cost**

Note. Adapted from the ACRP Resource Video on *Guidance for preparing Benefit/Cost Analyse*s (Byers, 2016)

The next phase of research and development involves creating a detailed plan for implementing the selected AAM design, considering the demand for the catchment area, unique infrastructure, and status of each airport. To complete this phase, it may be necessary to employ graduate student assistance for a full-time period of nine weeks. This would involve four weeks of research and assessment of the current airport status including the market research, three weeks of developing a step-by-step plan, and two weeks of obtaining feedback from the associated government and airport personnel and incorporating it into the plan. Table 11 indicates pertaining costs.

Table 11

Cost for Research and Development [Beta] phase

Item	Rate	Qty.	Total	Remarks
Labor – Market research and customizing a roadmap for an individual airport				
Students Efforts	$30/hr	720	$21,600	40 hours/week * 2 students * 9 weeks; Purdue University student rate ($30)
FAA Advisor	$120/hr	4	$480	2 hours * 2 people
Airport Personnel	$120/hr	8	$960	4 hours * 2 people from operation and maintenance
Expenses				
Travel	$7,500	Est.	$7,500	Assumes sponsored research budget
Subtotal			**$30,540**	*** One-time cost**

Note. Adapted from the ACRP Resource Video on *Guidance for preparing Benefit/Cost Analyse*s (Byers, 2016)

Once the items to be improved are identified, the airport should prepare for the necessary infrastructure improvements required by regulations and AAM operations. The cost analysis for the design includes considerations for all necessary aspects, even for GA airports without Part 139 Certification, taking a conservative approach. While the design is primarily intended for airports with previous commercial operations, it is essential to consider the potential costs and benefits for all airports to fully assess the economic feasibility of the proposed infrastructure changes. Table 12 outlines the estimated costs, which are divided into two categories: mandatory improvements required to comply with regulations, and recommended improvements aimed at enhancing the operation and service.

Table 12

Cost for Implementation phase

Item	Rate	Qty.	Total	Remarks
Part 139 Certificate prerequisites				
Manuals and plans	$50,000	LS	$50,000	Airport Certification Manual, Emergency response plan, Security plan, and Snow and Ice Removal plan
Security fence	$1,000,000	LS	$1,000,000	Linear mile of fence with pertaining assessment for improving
ARFF trucks	$750,000	1	$750,000	Index B, 1,500-gallon Truck
Snow removal equipment	$1,700,000	LS	$1,700,000	Sweeper $350K, Blower $750K, Plow $350K
Facilities for AAM operation				
Electricity Charger on ramp	$5,000	3	$15,000	2C rate chargers (Charge at 200 kW/hr)
Terminal Renovation	$700,000	1	$1,000,000	Sterile area, Holding area, Baggage handling area, Renovation
Car parking system	$150,000	1	$150,000	Automated access control and parking fee collect equipment
Subtotal			**$4,665,000**	

The Cost-Benefit Analysis seeks to compare the sums of all costs and benefits of a project, to determine if it is financially viable to proceed. If the estimates reveal a net positive outcome, the project should be pursued. If the project reveals a net negative outcome, the project should be abandoned. To quantify the viability of this project, the team utilized the US Dollar. To further break down the viability, the Benefit to Cost Ratio establishes how profitable the project is. A ratio between 0 and 1 produces a net profit but yields a return less than double the investment. If the project yields a ratio greater than 1, the project yields a return more than the amount invested and should be considered extremely beneficial.

The Cost-Benefit Analysis for this project produced a net positive, resulting in approximately $8,299,840 profit, from a $4,706,620 investment. Leading to a Benefit to Cost Ratio of 2.76. To estimate the 10 year's net yield and Benefit to Cost Ratio, totals from previous calculations were multiplied to produce 10-year totals, and the difference calculated between costs and income as described in Table 13.

Table 13

Benefit-Cost

Benefit	Rate	Qty	10 Year Total	Notes
AIP Grants	$774,200/year	10 years	$7,742,000	Refer to Table 8
Landside Income	$138,200/year	10 years	$1,382,000	Parking, Concessionaire
Airside Income	$459,718/year	10 years	$4,597,180	Landing, TSA rent, green fuel sale, PFC
Subtotal benefit			**$13,721,180**	
Cost	**Rate**	**Qty**	**10 Year Total**	**Notes**
R&D Alpha	$11,080	1 time	$11,080	Refer to Table 9 Spread across airports
R&D Beta	$30,540	1 time	$30,540	Refer to Table 10
Implementation	$4,665,000	1 time	$4,665,000	Refer to Table 11 Takes up to three years
Subtotal cost			**$4,706,620**	
Net Yield			**$9,014,560**	Net Profit
Benefit to Cost Ratio			**2.92**	Benefit Outweigh Cost

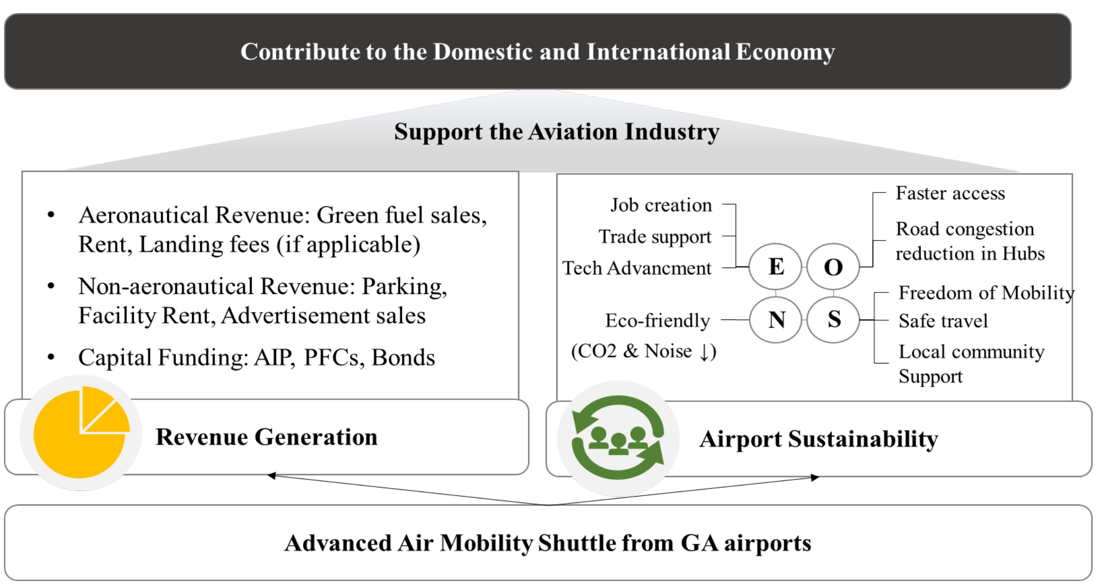
Note. The provided figures are approximate estimations and are subject to variation based on factors such as the size of the airport, existing infrastructure, and available personnel.

Sustainability Assessment

Janic (2011) defined sustainable development for airports as mitigating their environmental and social impacts, while accounting for their continued growth, and recent considerations include land use, congestion, and delays. Despite significant attention given to sustainable development, evaluating sustainability can be challenging due to different perspectives and definitions of the concept. One widely used approach for assessing sustainability is the Triple Bottom Line (TBL) method, which considers the economic, social, and environmental impacts of an activity or organization. The TBL approach emphasizes the need for businesses to monitor and manage value creation or depletion in each of these three areas (Elkington, 2018). Airports in the US commonly employ the EONS framework (Marete, 2019), which incorporates an operational component along with the three pillars of the Triple Bottom Line (TBL) method, for sustainability assessment and is also utilized by the FAA to depict airport sustainability (FAA, n.d.). The design aims to incorporate all dimensions of sustainability, demonstrating it using the EONS framework as shown in Figure 5.

Figure 5

Expected Impact of the Design



Economic

The integration of advanced air mobility (AAM) could bring in additional revenue streams for airport authorities and help them become financially self-sustainable. This is particularly significant for GA airports that often struggle to secure adequate funding for their operations. The increased revenue could also create new job opportunities for individuals involved in the design, manufacture, operation, and maintenance of AAM vehicles, and could boost the demand for skilled labor such as pilots, air traffic controllers, and engineers.

In addition to the economic benefits for airport authorities and job creation, the integration of AAM could also promote economic development by improving regional connectivity. With quick and efficient transportation options between remote locations and urban centers, AAM could become a game-changer for regional connectivity. This, in turn, could enhance the role of hub airports as a transportation hub, contribute to the advancement of the aviation industry, and have a positive impact on the national economy.

The integration of AAM could also encourage the implementation of innovative technology within the aviation industry, ultimately contributing to the global economy.

Operational

Regarding operational efficiency, the integration of advanced air mobility (AAM) as a shuttle to hub airports has the potential to offer faster travel times than traditional ground transportation, thus reducing travel times between destinations. This, in turn, can help reduce road and traffic congestion, particularly in busy airports, resulting in a more efficient and smoother passenger experience. Additionally, the integration of AAM could provide greater flexibility and freedom to travel to remote locations and difficult-to-reach areas, making travel more convenient and efficient. It can also reduce passenger transit and wait times, improving overall travel experience. Passengers often feel tired of waiting in long queues for boarding an aircraft. However, AAM is anticipated to have shorter check-in and security check times since the vehicle accommodates a small number of people and aims to have as short a turnaround time as possible. This means that passengers can spend less time waiting and more time enjoying their travel experience.

Natural Resources

The integration of advanced air mobility not only offers potential benefits to the economy and operational efficiency but also has a positive impact on the environment. AAM vehicles often use electric or hybrid engines, which produce lower carbon emissions compared to traditional gasoline engines, contributing to natural resource conservation efforts. Furthermore, they are designed to be quieter than conventional aircraft, reducing noise pollution and minimizing the impact on local communities. The reduction of carbon emissions and noise pollution is crucial to mitigating the effects of climate change and preserving the environment for future generations. Therefore, the integration of advanced air mobility is not only a promising solution for improving transportation but also for promoting environmentally sustainable development.

Social

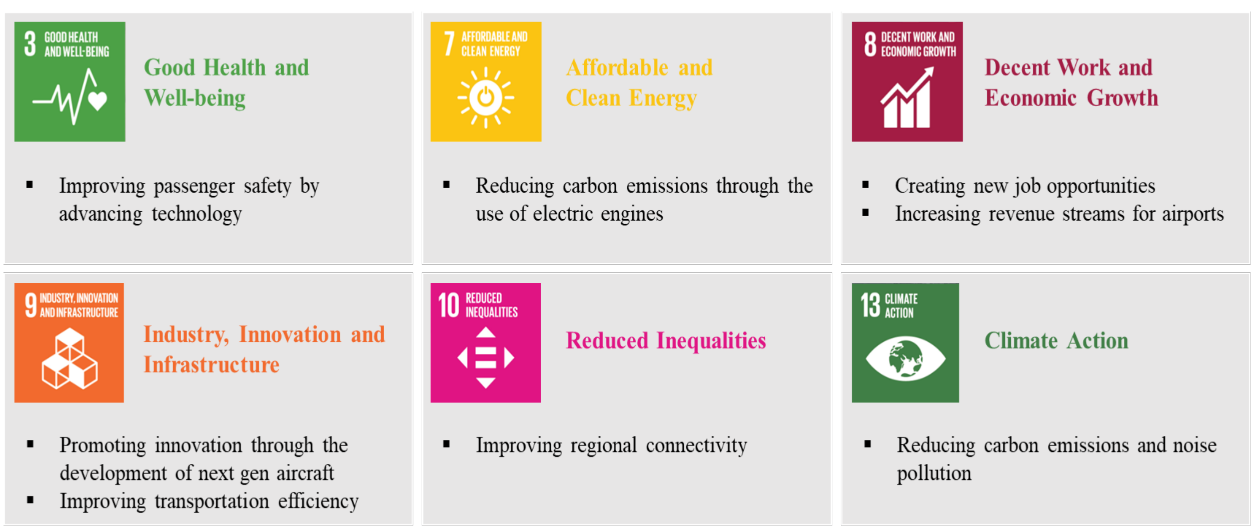
The proposed design of implementing AAM as a scheduled shuttle between GA airport and hub airport presents a significant social benefit by improving accessibility for people in underserved areas. The availability of convenient and efficient travel options will enhance connectivity among regions and stimulate local economic growth through indirect and induced spending. Furthermore, the design is in line with the current shift in transportation preferences that prioritize operational and biological safety. AAM offers potential benefits such as reducing congestion, providing a more efficient and predictable mode of transportation, and limiting the risk of infectious disease transmission by restricting the number of passengers in a vehicle. These features make AAM a resilient transport mode that can better prepare for unpredictable issues.

In addition, the integration of AAM can positively impact social responsibility by providing airports with community outreach through Science, Technology, Engineering, and Math (STEM) education. The proposed AAM commercial service can enable future generations of the aviation workforce to visually learn the inner workings of aviation operations, which can yield a return beyond monetary value for airports.

In summary, integrating advanced air mobility as a commercial service in airports aligns with several UN Sustainable Development Goals, including SDG 3, SDG 7, SDG 8, SDG 9, SDG 10, and SDG 13. These goals address economic growth, industry innovation and infrastructure, clean energy, climate action, and social equality, etc., as shown in Figure 6.

Figure 6

UN Sustainable Development Goals



Conclusion

For decades, GA airports have meagerly survived against the onslaught of defunding, mandated closures, and shrinking demand. Despite their constant defensive position, these airports have carried on their operations, piecing together their budgets and equipment through whatever means necessary. This design stands to change the status quo.

Serving as a road map for GA airports serving college towns, industrial/large organizational business, and are located 1-2 hours' drive away from a small-medium primary hub airport; the design aims to open/reopen sources of operating revenue and capital improvement funding by increasing passenger enplanements through the implementation of scheduled AAM flights. Once these airports become Primary Commercial Service Airports attaining 10,000+ enplanements, they can collect the $1,000,000 Nonprimary Entitlement Grant, or $1,000,000 Primary Entitlement and Passenger Entitlement Grant providing up to $15.60 per passenger (FAA, 2019; NASEM, 2019).

Additionally, this design will create several revenue streams through means such as: passenger parking fees, green energy fuel fees, airside facility usage fees, landside facility usage fees, passenger facility charges, in-terminal advertisement sales, etc. Thereby allowing airports to sell higher value: special facility revenue bonds, revenue bonds, and industrial development revenue bonds; that can directly assist in the financing of revenue generating investments or essential facility upgrades. In total, design implementation will generate an estimated $9,014,560 profit over a 10-year period. Finally, the design's goal includes leveraging the use of innovative technology and incorporation of the national vision of global leadership of aviation, to make a big play to boost the economy and science development.

Appendix A: Contact Information

Faculty Advisor

Mary E. Johnson, PhD, Professor

Purdue University, School of Aviation and Transportation Technology

mejohnson@purdue.edu

Student Information

Tanner Bowman

bowma142@purdue.edu

Junghye Lee

lee4127@purdue.edu

Appendix B: Description of University

Purdue University

"PERSISTENT INNOVATION. TOGETHER."

"Purdue University, the land, sea grant University in Indiana, is a vast laboratory for discovery. Purdue is a public university known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real – especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that's without rival." (Purdue, n.d.)

School of Aviation and Transportation Technology

"Purdue University's School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue's Aviation and Transportation Technology majors are world-class educational programs. The mission of the School of Aviation and Transportation Technology is to prepare the next generation of leaders and change agents for the transportation sector. The School will be the recognized global leader in aviation technology education through excellence in faculty, students, curricula, laboratories, and mutually beneficial partnerships" (Purdue, n.d.).

Appendix C: List of Industry Experts

Mr. Adam Baxmeyer is an experienced airport director with a diverse background in both commercial airports and GA airports. Prior to his current role at Purdue University Airport (LAF), Mr. Baxmeyer worked at Central Illinois Regional Airport at Bloomington-Normal and Cherry Capital Airport. His expertise in different airport types allows him to provide valuable insight and knowledge on their unique characteristics and the strategic vision required for successful operation.

Dr. Maria Muia is an experienced Senior Aviation Researcher and Senior Aviation Planner at Woolpert, where she focuses on addressing infrastructure planning and regulatory challenges for advanced air mobility (AAM), urban air mobility (UAM), electric vertical takeoff and landing (eVTOL), and unmanned aircraft systems (UAS). She is currently leading several key research projects for the FAA and other organizations to develop new standards and policies for vertiport design, airspace planning, and the use of large UAS at airports. With over 25 years of experience in both the public and private sectors, Dr. Muia brings a wealth of expertise in airport planning, management, funding, and regulatory compliance to her work in AAM and related fields.

Dr. Volodymyr Bilotkach is a distinguished professor of Aviation Management at Purdue University, with extensive expertise in aviation economics, regulation, policy, strategy, and statistics in commercial civil aviation. He is also a co-editor of the Journal of Air Transport Management, and his research interests span the entire aviation sector of the economy. Dr. Bilotkach's experience in advising airports across the world, along with his educational background in economics, enables him to see the bigger picture in his field.

Appendix E: Evaluation of the Educational Experience Provided by the Project

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

    The design competition was an enriching experience for the team, allowing us to apply our skills and knowledge to real-world problems and gain practical experience. Moreover, the competitions nurtured our creativity, innovation, and collaboration. As students from divergent backgrounds, we worked together to develop novel solutions and ideas. Working as a team we also learned how to improve our project management skills and to work systematically. Simultaneously, the chosen topic compelled us to keep up with the latest news and technological developments in the aviation industry, further instilling confidence and pride in our work. Finally, the competition provided us with a platform to connect with industry experts and build professional relationships, further expanding our knowledge and perspective of aviation beyond textbooks.

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

    Luckily, we were not met with any devastating challenges in this competition. However, we encountered strain while trying to choose our project's single topic. We were ambitious, and both presented numerous ideas that we wanted to explore. This enthusiasm resulted in our lack of focus; proving to be an obstacle in the project's initial stages.

To overcome this challenge, we approached the issue systematically. Both team members conducted independent research on potential topics, compiling information and opinions from our advisor. By gathering individual perspectives we were able to evaluate our ideas objectively and come to a consensus on a suitable topic. This method allowed us to channel our energy and ambition productively, leading to the design.

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

After selecting our topic, we began our hypothesis development by creating a "Systems Thinking" Map, to analyze the current state of the chosen area. Given that the topic we selected, Advanced Air Mobility, is a relatively new technology that has yet to be fully realized, we encountered a scarcity of literature to reference. Despite this challenge, we were able to use ACRP reports on UAM and GA airport operations as a guide for our design direction.

We also found industry experts to be an invaluable source of information. Their insights provided us a deeper understanding of the challenges and opportunities associated with our topic. Thereby allowing us to develop a more informed and effective hypothesis by utilizing a combination of systems thinking, research, and expert opinions. Thus, enabling us to craft a robust and compelling hypothesis for our project.

In developing our design proposal, our team took a pragmatic approach. Rather than attempting to create a completely novel solution, we drew upon lessons learned from previous best practices, including the hub and spoke model, as well as examining previously failed cases such as SATS. By analyzing these examples, we were able to identify potential pitfalls and design a solution that would be more likely to succeed.

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

    The participation of industry in our project was invaluable; proving to be appropriate, meaningful, and useful. The insights provided by industry experts surpassed what we could learn from literature alone, enabling us to consolidate and synthesize information more effectively. Our industry experts also helped identify weak points that we had not considered, leading to a more thorough and comprehensive design.

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?

    We say in solidarity, that this project has helped us to hone skills and knowledge that we previously perceived to be less formidable. Notably, we learned how to create a business proposal that can be adapted for real world use, and how to argue our research and design development within it. Secondly, we became experts in airport categories within NPIAS, in addition to grants, and AAM operations; allowing us to demonstrate our thorough research and understanding of the topic. This skillset will prove fruitful in our future studies or careers in the aviation industry. Most importantly, the project helped us to improve our communication skills. Teaching us how to effectively communicate despite our contrasts in nationality, primary language, and educational backgrounds.

Faculty

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

   Because the teams choose their challenge areas, they are more invested in the outcome and dedicate a great deal of time to the projects. Many of these students make contacts that will be a resource throughout their careers. The students gain more value when they can apply newly learned design skills and sustainability skills to a project that is based on real airport needs. While they learn theoretical information, the learning that occurs through team interaction and expert interactions cannot be easily replaced.

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

   This competition proposal was part of an independent study course with one graduate student and one undergraduate student. The course level and context are appropriate and a popular choice of project types.

3. What challenges did the students face and overcome?

   The team formed quickly and began seeking ideas to study. This unbridled creativity was great to see, but finally, the team had to settle on one idea and get to work. This project was done in one semester.

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

   I definitely will continue to use this competition as an educational vehicle. The knowledge the team gains in 12 weeks is irreplaceable through readings and shorter projects.

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

   I would add sustainability as an aspect of the project that should be addressed because this issue is challenging and is becoming requested by more communities and other stakeholders.

Appendix F: Reference List

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. *Transportation Research. Part A, Policy and Practice*, *132*, 696–712. https://doi.org/10.1016/j.tra.2019.12.020

Airport Cooperative Research Program University design competition for addressing airport needs. (2022*). 2022-2023 Design competition guidelines*. Airport Cooperative Research Program. Retrieved from https://vsgc.odu.edu/acrpdesigncompetition/wp-content/uploads/sites/3/2022/08/2022-2023-ACRPDesignGuidelines_v5.pdf

America map [Digital Image]. (2012). https://pixabay.com/images/id-35713/

American Eagle Flight 4184 (n.d.) History. Retrieved on April 2, 2023, from http://www.americaneagleflight4184.com/history.html

Archer. (2023). *Midnight*. Retrieved May 4, 2023, from https://www.archer.com/midnight

Bilotkach, V. (2018). Political economy of infrastructure investment: Evidence from the economic stimulus airport grants. *Economics of Transportation (England), 13*, 27–35. https://doi.org/10.1016/j.ecotra.2017.12.003

Cook, G. N., & Goodwin, J. (2008). *Airline Networks: A Comparison of Hub-and-Spoke and Point-toPoint Systems* . Retrieved April 6, 2023, from https://commons.erau.edu/cgi/viewcontent.cgi?article=1443&context=jaaer

Elkington, J. (2018) *25 years ago I coined the phrase "Triple Bottom Line." Here's why it's time to rethink it*. Harvard Business Review. https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it

Hussain, A., Silver, D. (2021, January) *Advanced Air Mobility: Can the United States afford to lose the race?*. Deloitte Insights. Retrieved from https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/advanced-air-mobility.html

Indiana Department of Transportation (2019). *2018-2019 Indiana Aeronautical Chart*. Office of Aviation. Retrieved on April 28, 2023, from https://www.in.gov/indot/div/pubs/2018-2019_Aero_Chart.pdf

Failla, S., Bivono, E., & Ventola, N. (2014). *Exploring Airports' Landside Congestion Impacts on the dynamic of Passengers Satisfaction*. System Dynamics Society. Retrieved from https://www.systemdynamics.org/assets/conferences/2014/proceed/papers/P1233.pdf

Federal Aviation Administration [FAA]. (n.d.) *Advanced Air Mobility | Air Taxis*.Federal Aviation Administration. Retrieved February 16, 2023, from https://www.faa.gov/air-taxis

Federal Aviation Administration [FAA]. (2019). *Airport Improvement Program Handbook* . Federal Aviation Administration. Retrieved from https://www.faa.gov/airports/aip/aip_handbook/

Federal Aviation Administration [FAA]. (2020a). *National Plan of Integrated Airport Systems 2021-2025*. Secretary of Transportation. Retrieved from https://www.faa.gov/airports/planning_capacity/npias/reports/

Federal Aviation Administration [FAA]. (2020b). *Urban Air Mobility (UAM) Concept of Operations (v1.0).* Federal Aviation Administration, U.S. Department of Transportation. https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf

Federal Aviation Administration [FAA]. (2022, August 3). *The White House Summit on Advanced Air Mobility*. Federal Aviation Administration. Retrieved February 11, 2023, from https://www.faa.gov/speeches/white-house-summit-advanced-air-mobility

Federal Aviation Administration [FAA]. (2023). Advisory Circular 150/5200-37A: Safety Management Systems for Airports. Retrieved April 2, 2023, from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5200_37A_Part_139_SMS.pdf

Federal Aviation Administration. *PFC Overview*. (2022). Retrieved April 18, 2023, from https://www.faa.gov/airports/central/pfc/pfc_overview

Fortune Business Insight (2022, February) *Urban Air Mobility (UAM) Market size, Share & Covid-19 Impact analysis*. Fortune Business Insight. https://www.fortunebusinessinsights.com/urban-air-mobility-uam-market-106344

Fu, M., Rothfeld, R., & Antoniou, C. (2019). Exploring Preferences for Transportation Modes in an Urban Air Mobility Environment: Munich Case Study. *Transportation Research Record*, *2673*(10), 427–442. https://doi.org/10.1177/0361198119843858

H2FLY. (n.d.). *Vision*. Retrieved May 4, 2023, from https://www.h2fly.de/vision

Janić, M. (2011) *Greening Airports: Advanced Technology and Operations*. Springer. https://doi.org/10.1007/978-0-85729-658-0

Joby. (2023). *Joby Aviation*. Retrieved May 4, 2023, from https://www.jobyaviation.com/

Johnson, W. C. (2019). *UAM Coordination and Assessment Team (UCAT) NASA UAM for ENRI Technical Interchange Meeting*. National Aeronautics and Space Administration [NASA]. https://ntrs.nasa.gov/api/citations/20190025373/downloads/20190025373.pdf

Jonas, A. (2019). *Are Flying Cars Prepared for Takeoff?*. Morgan Stanley. Retrieved on February 23, 2023 from https://www.morganstanley.com/ideas/autonomous-aircraft

Kaps, R. W., NewMyer, D. A., Lanman, R. T., & Sigler, J. (2001). The Need for Airport Funding. *Collegiate Aviation Review, 19(1)*, 71-91. https://doi.org/10.22488/okstate.18.100299

Kolos-Lakatos, T. (2021) *The Future of Advanced Air Mobility (AAM) and What it Means for Airports*. InterVISTAS. Retrieved on March, 9, 2023, from https://www.intervistas.com/wp-content/uploads/2021/11/The-Future-of-Advanced-Air-Mobility_InterVISTAS_Nov2021-1.pdf

KSA (2021) *2020 General Aviation Airports Rates & Charges Survey*. Retrieved on May 3, from https://ksaeng.com/sites/default/files/2021-05/Aviation%20Rates%20and%20Fees%202020%20Final.pdf

LoopNet (n.d.). *Frequently Asked Questions*. Retrieved on May 4, 2023, from https://www.loopnet.com/search/office-space/west-lafayette-in/for-lease/#:~:text=The%20average%20cost%20for%20Office,Space%20in%20West%20Lafayette%2C%20IN.

Malik, T. (2004) *NASA sets stage for personal aircraft.* NBC News. Retrieved on March 19, 2023, from https://www.nbcnews.com/id/wbna5750922

Marete, C. K. (2019) *Incorporating sustainability planning in airport master plans: A case study of six U.S small hub airports* [Master's Thesis, Purdue University].

Millsaps, G. (2003, March). *Small Aircraft Transportation System Simulation Analysis of the HVO and ERO Concepts*. Federal Depository Library Program. Retrieved March 21, 2023, from https://permanent.fdlp.gov/gpo19373/20030032177-2003026069.pdf

Municipal Securities Rulemaking Board [MSRB]. (2018). *Six Things to Know When Issuing Municipal Bonds*. Retrieved April 18, 2023, from https://www.msrb.org/sites/default/files/MSRBSixThingstoKnow.pdf

National Aeronautics and Space Administration [NASA]. (2001). *SATS: A Bold Vision*. Retrieved April 6, 2023, from https://www.nasa.gov/centers/langley/news/factsheets/SATS.html

National Aeronautics and Space Administration [NASA]. (2021). *Advanced Air Mobility National Campaign Partners.* Retrieved April 26, 2023, from https://www.nasa.gov/aeroresearch/advanced-air-mobility-national-campaign-partners

National Academies of Sciences, Engineering, and Medicine [NASEM]. (2008) *ACRP Report4: Ground Access to Major Airports by Public Transportation.* The National Academies Press. https://doi.org/10.17226/13918

National Academies of Sciences, Engineering, and Medicine [NASEM]. (2009) *Guidebook for Managing Small Airports.* The National Academies Press. https://doi.org/10.17226/14275

National Academies of Sciences, Engineering, and Medicine [NASEM]. (2011) *ACRP Report 54 Resource Manual for Airport In-Terminal Concessions*. The National Academies Press. https://doi.org/10.17226/13326

National Academies of Sciences, Engineering, and Medicine [NASEM]. (2019) *Guidebook for Managing Small Airports - Second Edition*. The National Academies Press. https://doi.org/10.17226/14275

National Academies of Sciences, Engineering, and Medicine [NASEM].(2023) *ACRP Research Report 243: Urban Air Mobility: An Airport Perspective*. The National Academies Press. https://doi.org/10.17226/26899.

PricewaterhouseCoopers. (2020) *Contribution of General Aviation to the US Economy in 2018.* PricewaterhouseCoopers LLP. Retrieved February 27, 2023, https://nbaa.org/wp-content/uploads/advocacy/legislative-and-regulatory-issues/business-aviation-essential/General-Aviation-Contribution-to-the-US-Economy-20200219.pdf

Purdue University. (n.d). *About.* About the School of Aviation and Transportation Technology. Retrieved March 20, 2023, from https://polytechnic.purdue.edu/schools/aviation-and-transportation-technology/about

Sameh, M., & Scavuzzi dos Santos, J. (2018). Environmental Sustainability Measures for Airports. In A. De Mestral, P. Fitzgerald, & M. Ahmad (Eds.), *Sustainable Development, International Aviation, and Treaty Implementation (Treaty Implementation for Sustainable Development, pp. 62-80).* Cambridge: Cambridge University Press. doi:10.1017/9781316594216.005

Schreiner, J. & Salado, A. (2019). Systems Engineering. In Shah, H. & Nowocin, W (Eds.), *A Guide to the Engineering Management Body of Knowledge (pp. 227-252)*. The American Society for Engineering Management

Senge, P. (1994). *The Fifth Discipline Fieldbook: Strategies and tools for building a learning organization.* CurrencyDoubleday.

Shahid, S., Agelin-Chaab, M. (2022) A review of thermal runaway prevention and mitigation strategies for lithium-ion batteries. *Energy Conversion and Management: X*, 16, https://doi.org/10.1016/j.ecmx.2022.100310

The White House. (2022, August 5). *Readout of the White House Summit on Advanced Air Mobility* [Press Release]. Retrieved February 11, 2023, from https://www.whitehouse.gov/ostp/news-updates/2022/08/05/readout-of-the-white-house-summit-on-advanced-air-mobility/

Transportation, 49 U.S.C §47102 (1994).

Transportation Research Board [TRB]. (2002). *Special Report 263 Future Flight: A Review of the Small Aircraft Transportation System Concept*. The National Academies Press. https://doi.org/10.17226/10319.

Smashicons (n.d.) *UAM* [Digital Image]. https://www.flaticon.com/free-icons/drone

Virginia Space Grant Consortium. (2016, September) *Completing a Safety Risk Assessment* [Video]. YouTube. https://youtu.be/PX5GFC_RNYo

Virginia Space Grant Consortium. (2021, August) *Guidance for Preparing Benefit/Cost Analyses* [Video]. YouTube. https://youtu.be/J1yRM1uPpcc

Warwick, G (2023) *AAM Leaders Grapple With Traditional Aerospace Issues*. Aviation Week. Retrieved on March 20, 2023, from https://aviationweek.com/aerospace/advanced-air-mobility/aam-leaders-grapple-traditional-aerospace-issues

Weitering, H. (2023) *Archer and United Airlines Reveal First Air Taxi Route in Chicago*. Future Flight. Retrieved April 5, 2023, https://www.futureflight.aero/news-article/2023-03-23/archer-and-united-airlines-reveal-first-air-taxi-route-chicago

Z. Zgodavová, R. Rozenberg and S. Szabo, "Analysis of Point-to-Point versus Hub-and-Spoke airline networks," *2018 XIII International Scientific Conference - New Trends in Aviation Development (NTAD)*, Košice, Slovakia, 2018, pp. 158-163. https://ebookcentral.proquest.com/lib/purdue/reader.action?docID=3377923&query=