Integration of Advanced Air Mobility Corridors into the National Airspace System

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Technology

Approved July 2023 by the
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ARIZONA STATE UNIVERSITY

December 2023

ABSTRACT

With the rapid advancements in aviation technology, the concept of Advanced Air Mobility (AAM) has gained considerable attention as a potential solution to address the growing demands for urban transportation. AAM refers to the use of electric vertical takeoff and landing (eVTOL) aircraft for short-haul flights within urban and suburban areas. However, the implementation of AAM systems requires careful evaluation of feasibility, considering the existing structure of the National Airspace System (NAS) and local planning considerations. This research paper presents a comprehensive framework to assess the feasibility of AAM corridors in urban environments. Firstly, the integration aspect focuses on evaluating the compatibility of AAM operations with the existing airspace infrastructure. The framework assesses the potential impact of introducing AAM corridors on airspace capacity, safety, efficiency, and environmental sustainability. Additionally, it explores the required modifications or upgrades to existing NAS infrastructure to accommodate AAM operations. Secondly, the framework addresses local planning considerations, acknowledging that AAM corridors operate within specific urban or suburban landscapes. It considers factors such as land use, noise levels, public acceptance, emergency response capabilities, and integration with existing transportation networks. The framework provides decision-makers, urban planners, and aviation stakeholders with valuable insights into the feasibility of implementing AAM corridors, enabling informed policy decisions, infrastructure planning, and the development of regulation to support the safe and efficient deployment of AAM systems.

ACKNOWLEDGMENTS

First of all, I would like to show appreciation to Professor Michael Cirillo, who kindly offered to serve as the chair of the committee steering this thesis and volunteering his network connections across the Federal Aviation Administration and beyond to help inform the research presented in this thesis. Throughout my graduate studies I faced many challenges due to having an incredibly busy schedule between work and school, so your understanding and encouragement to complete my thesis was much needed and appreciated. Completing a research thesis is something that I have been excited to work on since my arrival at Arizona State University in late 2019, so to have a supportive chair to enable me to fulfill this educational goal of mine has meant the world to me.

To Marc O’Brien, thank you for your continued support across all four years of study at Arizona State University. Both as your student and your employee in the aviation program, every interaction made me feel welcomed and supported to achieve my goals. In just my first semester, you allowed me to explore various niche careers in aviation management for honors credit, a project which opened my eyes to the vast opportunities that my studies at ASU would allow me to pursue. In the following years as your employee while providing administrative support and recruiting services for the aviation program, your friendship and support made me feel like part of the aviation family here at ASU which is something I will be forever grateful for.

To Craig Drew, whose lectures captured the imagination of how aviation companies of all kinds, not just airlines, could embrace cultures of safety, innovate, and push the industry forward from what it is today. Our conversations consistently captured

the imagination and led me to dream of what is possible for our industry beyond the status quo.

This research would not have been possible without the help of Jeff Borowiec, Ph.D., who provided invaluable insight and reference towards determining how advanced air mobility will change the way we travel. Dr. Borowiec has been supportive of my research and academic pursuits in the planning and development space since my undergraduate years at ASU, so his continued support culminates with this thesis continuing towards my goals in aviation research.

Additional thanks to David Sperling, who formerly taught graduate coursework on airport planning and design at Arizona State University. The course he taught was instrumental to lighting the fire that evolved into an interest in aviation planning. No amount of additional questions expanding on each topic was too much, and for that I am grateful for your expertise and the impact it has had on how I conceptualize planning and innovation at aviation facilities.

Completing my education at Arizona State University would not have been possible without the generous support of Justin and Natalie Firestone, Phoenix Sky Harbor International Airport, and the Foundation for Allen Schools. Without scholarships offered by these generous individuals and organizations, I would not have been able to continue past my undergraduate studies to achieve the completion of my master’s program, which has been a lifetime achievement goal of mine. The support of these scholarships is instrumental not only to me, but to allow ASU aviation grads to reach new heights and fulfill their dreams in the aerospace and transportation industries.

Special thanks to Leah Whitfield and Justin Heid of The Aviation Planning Group, who graciously allowed an undergraduate student with no experience in planning to dive headfirst into airport planning and design. Without the two of them allowing me to explore the interest I had in airport planning, I am not sure I would have been able to pave the path towards being a professional aviation planner. The experiences I gained throughout the spring of 2022 while creating ramp and taxiway alternatives for future development of Orcas Island Airport in Eastsound, Washington introduced me to all of the concepts and skills that would go on to be essential to my professional skill set in future work. Invitations to discussions on regional air mobility hosted by the Transportation Research Board further inspired some of the ideas discussed in this research.

Finally, and most importantly, I would like to extend my gratitude to my loving parents who have been lifelong inspirations to me. My father, George, has always been an icon of hard work and determination being a pathway to a better future. My mother, Christine, whose service to the community through education has inspired a lifelong pursuit of knowledge and the desire to someday share my own knowledge and experience with the next generation of aviation professionals. Without the support and love from both of them throughout my academic career, I would not be where I am today, and I would not be ready to open my next chapter of life with a dream profession where my work can have tangible impact on the lives of others by bringing economic opportunity and connection to communities. I am who I am today because of the many lessons and experiences I have gained from being your son.

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INTRODUCTION

Introduction to Advanced Air Mobility

Advanced Air Mobility (AAM) refers to the emerging class of air transportation services that utilize advanced technologies and innovative design to enable new types of aerial transportation, such as electric vertical takeoff and landing (eVTOL) aircraft, urban air taxis, and regional air shuttles (Pons-Prats et al., 2022). The primary objective of AAM is to offer faster, more efficient, and more sustainable transportation options, particularly in urban and suburban areas where ground transportation is congested and slow.

AAM has the potential to revolutionize transportation by providing on-demand, point-to-point air travel that is both affordable and less carbon intensive compared to existing aviation and public transport systems. These advanced technologies encompass electric propulsion systems, lightweight materials, autonomous flight capabilities, and advanced air traffic management systems. By harnessing these advancements, AAM aims to alleviate traffic congestion within existing infrastructure, reduce travel times, and minimize carbon emissions, contributing to a greener and more efficient transportation landscape.

The commercialization of AAM technologies can take various forms, including traditional airline models, ride-hailing services, or other mobility-as-a-service platforms. Additionally, niche applications such as cargo delivery, emergency medical personnel and equipment transport, and search and rescue operations are being explored to optimize existing operations. Companies are actively engaged in the development and testing of eVTOL aircraft and the necessary associated infrastructure to support these new modes of transportation. Successfully integrating AAM into existing transportation networks would require significant coordination among regulatory bodies, infrastructure providers, and service operators.

The use of smaller AAM aircraft for the delivery of goods is also gaining attention, particularly for last-mile logistics in urban areas (Mid-Atlantic Aviation Partnership, n.d.). Delivery drones equipped with advanced sensors and navigation systems have the potential to efficiently transport packages and goods directly to customers, bypassing ground-based traffic and reducing delivery times. This approach could revolutionize the e-commerce industry and enhance supply chain efficiency. Several test markets have already witnessed large e-commerce platforms evaluating the market feasibility of utilizing AAM for this purpose.

There are two main classifications within AAM that pertain to aircraft and capabilities with similar missions but differing technologies (Wolff, 2021). Urban Air Mobility (UAM) refers to the use of innovative aircraft (including eVTOL, hybrid, and hydrogen propulsion) for short-distance, point-to-point transportation within urban or suburban areas. This could involve air taxis transporting passengers between designated vertiports, heliports, or helipads, effectively reducing travel time and alleviating road congestion. Additionally, drones can be deployed for various purposes, including delivering goods and conducting aerial inspections. On the other hand, Regional Air Mobility (RAM) involves the utilization of larger eVTOL and eSTOL (electric short takeoff and landing) aircraft or redeveloped general aviation aircraft for regional transportation between cities and towns. These aircraft could offer faster and more efficient transportation options for individuals traveling between nearby cities or suburbs, as well as for business travel between regional hubs. By utilizing the vertical or short takeoff and landing capabilities of eVTOL and eSTOL aircraft, regional air shuttles can bypass the need for traditional airports and enable point-to-point travel over shorter distances.

Figure 1:Joby Aviation UAM-Type Aircraft | Figure 2:X-Wing RAM-Converted Aircraft

(Sources: (left) Joby Aviation Press Kit, 2022 | (right) X-Wing Press Kit, 2023)

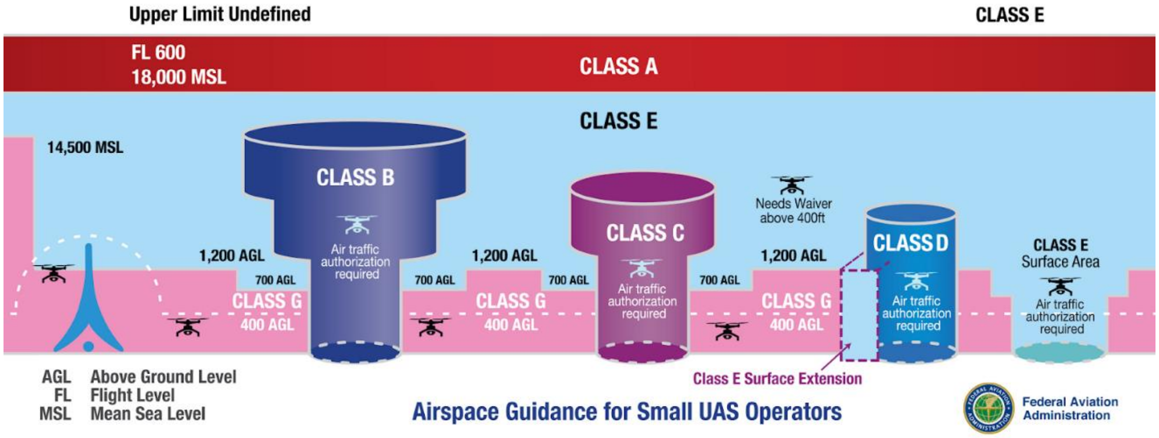
AAM represents an exciting new frontier in transportation that has the potential to transform the industry for both people and goods in the years to come. Although numerous regulatory and logistical challenges need to be addressed, the potential benefits of AAM make it a promising area of innovation and investment for the future. Regulators, manufacturers, and researchers are diligently working to develop frameworks and solutions to effectively manage this convergence of technology, mobility, and safety. As technology continues to advance and infrastructure evolves, AAM has the potential to reshape urban mobility, enhance connectivity, and contribute to a more sustainable transportation ecosystem.

Existing National Airspace System Structure

The National Airspace System (NAS) is a complex hierarchical network of airspace, airports, air traffic control facilities, and other components that enable safe and efficient air transportation in the United States (Aeronautical Information Manual, 2023). The purpose of the NAS is to facilitate the movement of aircraft, passengers, and cargo through the airspace while minimizing delays and maximizing efficiency. Since its establishment, the NAS has been in a continual improvement process to enhance safety and efficiency for all users.

At the core of the NAS structure are airports, organized in a hierarchical manner. Hub airports, which are typically the largest and busiest, serve as critical connectors, linking smaller airports and regional centers. These hubs play a pivotal role in enabling seamless air travel by facilitating the efficient flow of passengers and goods. To monitor and manage aircraft movements throughout the system, the NAS incorporates various air traffic control facilities, including airport traffic control towers, terminal radar approach control facilities, air route traffic control centers, and associated traffic flow management units and facilities.

Figure 3: Diagram of NAS airspace classifications including present UAS limitations



(Source: Federal Aviation Administration “Airspace 101 - Rules of the Sky”, 2021)

In recent years, the NAS has undergone substantial enhancements through the implementation of metroplex airspace locations. These areas comprise highly congested airspace near major urban centers. Recognizing the need to address the challenges posed by congestion, the Federal Aviation Administration (FAA) has introduced advanced air traffic management technologies and procedures in metroplex airspace (U.S. Department of Transportation Office of the Inspector General, 2019). These technologies leverage satellite-based navigation and communication systems, enabling more precise and efficient routing for aircraft. Additionally, newly introduced technologies improved information sharing and collaboration between air traffic controllers and airline operators, leading to enhanced situational awareness and decision-making. The adoption of metroplex airspace locations has yielded positive results, notably in some of the busiest airports in the country, such as New York, Los Angeles, and Dallas-Fort Worth. By optimizing airspace utilization and mitigating congestion, these improvements have effectively reduced delays and increased capacity. Travelers and airlines have benefited from smoother operations and more reliable schedules, while the overall safety and efficiency of the NAS have been significantly enhanced.

Continued advancements in technology and operational practices will remain crucial for further enhancing the NAS. The integration of emerging technologies, such as unmanned aerial systems and advanced data analytics, holds promise for optimizing airspace utilization and enabling safe and efficient operations. Additionally, ongoing collaboration among stakeholders, including the FAA, airlines, general aviation stakeholders, airports, and air traffic controllers, will be vital to identifying and implementing innovative solutions that address the evolving needs of the air transportation system. Through these collaborative efforts, the NAS will continue to evolve, ensuring the continued growth and improvement of air transportation in the United States.

Statement of Purpose

The concept of advanced air mobility involves the use of new forms of aviation technology to transport passengers and goods in a more efficient and sustainable way. This innovative approach has the potential to revolutionize the transportation industry, offering benefits such as reduced congestion, lower emissions, and faster travel times. However, realizing the full potential of advanced air mobility requires addressing significant challenges that come with its implementation. One critical challenge that must be tackled is the safe and efficient integration of AAM operations within the existing

NAS. This necessitates collaboration among various stakeholders, including aerospace engineers, aviation planners, air traffic managers, and commercial operators. Helicopter-oriented operations such as medevac flights, law enforcement, and other unique operational demands further complicate airspace priorities. Each of these stakeholders brings a unique perspective and set of concerns that must be considered when developing a comprehensive plan for advanced air mobility.

Despite ongoing discussions and efforts by regulatory bodies and industry professionals, there is a risk that practical limitations faced by each profession may not be adequately addressed in the planning and implementation of AAM. For instance, aerospace engineers may primarily focus on the technical aspects of the technology, while air traffic managers may prioritize operational considerations. To ensure a successful integration, a comprehensive plan must strike a balance between these perspectives and accommodate the competing interests to achieve the safe and efficient incorporation of AAM into the NAS.

Additionally, the scale and volume of AAM operations could be substantial, requiring careful planning and coordination. Managing this ecosystem entails addressing potential impacts on existing air traffic and infrastructure, as well as developing new operational procedures to ensure the safe and efficient use of this technology. By proactively addressing these challenges, the industry can maximize the benefits of AAM while minimizing any disruptions to the existing airspace system.

Many use cases for advanced air mobility propose regional and inter-urban transport of passengers over distances that would traditionally be considered inefficient for full-scale commercial aviation. Considering this, the research will primarily focus on the development of a framework for implementing bespoke AAM corridors between congested centers of urban airspace. The goal is to enhance safety and manage the interaction between AAM aircraft and traditional fixed-wing aircraft or rotorcraft, which the existing NAS was designed to support. Additionally, considerable attention will be given to ensuring that these new AAM corridors do not conflict with existing metroplex airspace, which is already highly optimized for efficient operations. By designing specific corridors for AAM, the industry can streamline operations, improve safety, and effectively integrate this new mode of transportation into the existing airspace infrastructure.

This study, however, does not address all issues preventing total integration of AAM into the NAS at the present moment. Various academics continue research into management, safety, and other issues revolving around introducing AAM into the aviation and transportation industries. Government agencies similarly are working worldwide to address issues on a variety of topics including air traffic management, operational flight regulation, safety and navigational equipment requirements, and how existing air traffic might interact with AAM in a shared environment. This includes establishing the priority of airspace access for AAM operations compared to traditional NAS operations. All of these topics are still at various levels of research and development and will continue to influence planning practices in the future. Before local planning may commence as outlined later in this study, the regulatory and operational framework of AAM must continue to mature, which is likely as test aircraft have begun to demonstrate their abilities. With these limitations acknowledged, it is possible to begin to develop a basic framework for AAM corridor siting using both existing NAS resources and examining intergovernmental topics which could shape local factors in development.

Research Statement

Because of differences in aircraft performance capabilities, flight paths, and increasing levels of autonomous flight when compared to traditional small, manned aircraft, alterations to air traffic management structure and National Airspace System in the urban environment is necessary to ensure safe and efficient operations with the implementation of advanced air mobility. The primary objective of this study is to identify challenges and propose the criteria, regulations, and conditions needed in a framework for interagency planning which can best aid the implementation of AAM corridors into the NAS.

CHAPTER 2

LITERATURE REVIEW

Expanding the Scope of Traffic Management

To begin to dissect how AAM will factor into the NAS, it is important to understand how the largest aviation market in the world is beginning to establish a regulatory framework for managing advanced technologies such as AAM. The FAA and other nations consider all traffic management related activities to fall under the scope of Air Traffic Management (ATM). What many consider today as air traffic control (ATC) is part of a subset of ATM known as Air Traffic Services (ATS) which also includes Traffic Flow Management (TFM). TFM and its services complement the processes of ATC (Teperi, 2012). ATS composes many of the air traffic related activities today including the control of airliners, business jets, small general aviation aircraft, and helicopters and related data. ATS however does not cover the activities of unmanned aerial systems (UAS), the topic of this study within Urban Air Mobility (UAM), or high-altitude operations that fall into Upper Class E airspace within the existing NAS (although this realm of xTM is irrelevant to the subject of this study). To address this, under the scope of ATM, alongside ATS the FAA now includes the concept of Extensible Traffic Management Services (xTM) as a solution for incorporating the aforementioned advancements in aviation into the controlled airspace environment (Magyarits, 2022). As it pertains to airspace organization, cooperative operation is key to the success of blending xTM and ATS operations in designated airspace that is informed by the needs of the community of operators in the space, including low-altitude UAS and AAM operators. As aircraft transit through airspace already covered in the NAS by ATC, there will become a balance between xTM and ATM, similar to how aircraft today might go from a controlled Class B airspace to an uncontrolled Class G airspace.

Figure 4: Hierarchy of Air Traffic Management including ATS and xTM

(Source: Magyarits, 2022)

Utilization of Existing Resources

The National Airspace System contains many navigational and traffic management resources which airspace planners will be able to lean on when developing location-specific solutions for the introduction of advanced air mobility in the urban environment. A wealth of resources exists on the navigational front that are already in use within the NAS. Numerous ground- and satellite-based navigational technologies already assist in the management of traffic and navigation of aircraft. These technologies will be available for use by AAM aircraft operations as well and can form a strong baseline for navigational infrastructure (Levitt et al., 2023). The use of existing air traffic control systems, navigational aids, and highly standardized routes along airways could all be elements of the NAS which transfer into the management of AAM.

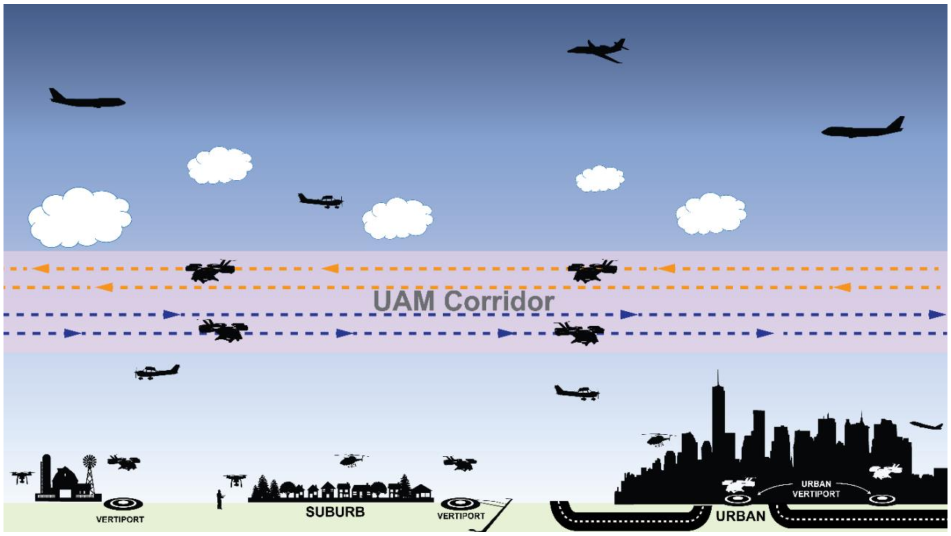
Resources available to planners can also exist beyond the scope of just aviation. As noted at various points throughout the case studies performed later in this study, collocation with other transportation infrastructure can provide benefit to both the regulatory hurdles around corridor siting and increase the likelihood of transportation mode transfer to solve last-mile travel to or from the vertiport (Mendonca et al., 2022). Collocation also mitigates the risk of environmental challenges or compensation related to routing. The United States does have legal precedent that navigable airspace can extend above private properties; however, low altitude flying in specific instances detrimental to the property and directly caused by low altitude operations can result in compensatory payments (United States vs. Causby, 1946). By collocating a corridor over existing transportation infrastructure such as highways or railroads, this issue can be generally avoided due to the right-of-way setbacks already established between this infrastructure and most private property.

Building from the FAA Vision

One of the guiding documents for the maturing development of AAM is the FAA Urban Air Mobility Concept of Operations (UAM ConOps). The ConOps outlines the operational concepts, procedures, and requirements for the safe integration of AAM operations into the NAS of the United States. The ConOps was published with the aim to establish a common understanding between stakeholders regarding the roles and responsibilities involved in UAM operations. The importance of the ConOps directly discusses guidance for the development of dedicated air corridors. Identified areas of focus for the success of corridors include the design, implementation, and management, including factors such as airspace structure, communication protocols, traffic management systems, and integration with existing air traffic management infrastructure (FAA ConOps, 2023). The ConOps can be seen as a crucial document in shaping future regulatory framework, infrastructure development, and operational procedures necessary for the successful integration of AAM operations into urban environments.

The most relevant section of the ConOps to the development of AAM corridors is section 4.4, entitled as such to discuss the transition to a corridor, traffic management, and corridor siting in the urban environment. Many of the topics discussed in this section of the ConOps have been further discussed within the aviation and academic communities as to how each problem addressed can be developed to maturity.

Figure 5: Illustration of a basic AAM corridor



(Source: FAA Urban Air Mobility Concept of Operations, 2023)

Entering and exiting corridors is a complex topic of discussion. There is a debate regarding whether corridors should have specific Corridor Entry/Exit Points (CEPs) or if the corridors should act as traditional airways already in the NAS that can be routed through any number of interchanging pathways with waypoints that can be used independently. CEPs do not need to be solely at the beginning and end of a corridor; however, to provide access to many urban vertiports in intra-urban corridors and intermediate stops along inter-urban corridors, entry and exit points can be identified in many spots along a routing (Bankole, 2023). CEPs would apply in highly congested airspace within the AAM environment to transition aircraft from the corridor to their destination or another airspace environment. CEPs may not be static, as in concept they would be points located though GPS-enabled navigation unlike more traditional fixes and waypoints established in reference to radio-based navigational aids. In times when AAM corridors must be adjusted or re-routed to avoid congestion in either nearby shared airspace or within the AAM corridor, dynamic management of CEPs is one key element of managing AAM traffic in the emerging xTM environment.

At maturity, AAM will encompass a multitude of aircraft classes, characteristics, and performance capabilities operating within a relatively congested environment. Present UAS regulation primarily involves a "See-and-Avoid" strategy when within visual line of sight (FAA ConOps, 2023). While this works at the moment, conflict avoidance similar to that of Visual Flight Rules (VFR) may not meet required safety standards. To mitigate safety risk, Demand-Capacity Balancing (DCB) can be employed within xTM to offer automated or human-reviewed air traffic management services to ensure safe and efficient operations, similar to the services currently provided by ATS.

As outlined in the ConOps, DCB in the xTM environment will also evaluate fluctuations in demand that may necessitate implementation of traffic management initiatives. The TFM structure in ATS is quite complex, and although it is highly automated, it remains human-centered. The xTM federated network will be predominantly automated. xTM service suppliers will leverage automation to facilitate autonomous operations, which is a key factor many AAM manufacturers are seeking to achieve. The integration of intelligent machine automation for UTM can solve traffic congestion in the urban environment using DCB to alleviate the likelihood of conflict or efficiency loss within AAM corridors (Pongsakornsathien et al., 2021). Some dense areas may still need active radio-based controlling communication, which can be defined through a demand-based study analysis when siting AAM corridors (Keeler et al., 2021). Ultimately, leveraging rapid automation in the cockpit and through UTM will aid in ensuring that within AAM corridors there is appropriate spacing for safety.

The ConOps highlights that currently, there is a lack of Standard Operating Procedure (SOP), or a framework specifically designed for the creation of these corridors. Consequently, it becomes imperative to adopt a planning and community inclusive framework for siting AAM corridors (FAA ConOps, 2023). To address this gap, it is crucial to engage with local and regional stakeholders. By involving various community members and organizations, their perspectives, concerns, and expertise can be considered during the decision-making process. External factors, such as urban planning, environmental considerations, and socioeconomic dynamics, may have a greater impact on determining the optimal locations for AAM corridors. Therefore, it is necessary to thoroughly examine these factors and understand their implications. The subsequent sections of this literature review will delve deeper into the engagement of local and regional stakeholders to explore how their involvement can contribute to the planning and implementation of AAM corridors, ensuring that the corridors not only meet aviation requirements but also address the broader needs of the communities for which they may have some level of impact.

While yet to be fully developed and supported by the FAA, researchers at NASA have also proposed Digital Flight Rules (DFR) as an alternative to the existing Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) (Wing et al., 2022). DFR enables the desired technological advancements in air traffic management in the xTM environment, including available onboard computational abilities for traffic avoidance. The application of DFR would not be exclusive to AAM users to the NAS. DFR is a critical component of a cooperative airspace environment in which traditional NAS users and AAM users coexist safely.

Perspectives Outside of the United States

London, England is a highly saturated helicopter market, which has seen increasing interest for AAM. A consortium of efforts led by Eve Air Mobility produced a Concept of Operations for United Kingdom airspaces. Among notable differences from the FAA ConOps that addresses the United States' NAS, the UK ConOps denotes that reclassifications of airspace and creation of new airspace classes may be necessary (UK Air Mobility Consortium, 2022). Compared to the somewhat distinct difference between ATS and xTM airspaces in the FAA's practice, this UK approach appears to be far more integrated into an airspace system which in some cases may better accommodate xTM-like operations. Where required, all UTM operations, even if not in controlled airspace, would be limited to flight planning and routing procedures more similar to what one would see in the U.S. with Instrument Flight Rules (IFR); whereas the FAA ConOps largely refers to traffic procedures and separation more in line with VFR (UK Air

Mobility Consortium, 2022) (FAA ConOps, 2023). This difference aside, the UK's plan does detail a high-level strategy for airspace management similar to what is seen with Demand-Capacity Balancing in the form of Dynamic Airspace Management.

Brazil has also begun to set out a road map for additional structure within the airspace system to address the introduction of AAM. It is important to note that this Brazilian report was completed by Eve Air Mobility through a large working group so there is strong potential for similarity to that of the UK ConOps. A stark difference to some of the research and hypothetical work done with corridors in the United States is that the Rio de Janeiro Concept of Operations published by regulator ANAC specifically notes separate corridors for eVTOLs, helicopters, and other UAS technologies segregated by technological capabilities (ANAC, 2022). While not explicitly mentioned in other literature in the FAA or UK ConOps, it would be assumed that in order to maintain the machine-assisted UTM environment, segregated pathways or varying altitudes accessible within a corridor may be necessary for aircraft such as older helicopters which may classify for UAM but without being purpose built will not have UTM-specific equipment on board nor accompanying autonomous communications and navigation.

AAM Performance Constraints

One of the key challenges facing regulators and operators is how to design airspace that is specifically tailored to the unique requirements of AAM aircraft that are presently in development. Speed and noise-related performance are two important factors that will have a significant impact on the design of airspace for UAM.

First, speed is a critical factor in determining the appropriate airspace design needed for UAM operations. Unlike traditional aviation, UAM aircraft are designed to operate at lower altitudes making it necessary to create airspace that is tailored to their unique operating characteristics at speed. While navigating the urban environment speeds may be in the expected slower ranges as would a helicopter during critical phases of flight; cruising speeds for aircraft capable of inter-urban transport may exceed 160 knots (Garrow et al., 2021).

Second, noise is another important factor that will influence the design of UAM-specific airspace. UAM aircraft are expected to produce less noise than traditional helicopters, but they will still generate a significant amount of noise in urban areas (Rizzi et al., 2020). Due to flying at very low altitudes with reasonable speed, noise pollution is inevitable. Noise can be impacted by a number of factors such as audience location, the built environment, distance, and more. As a result, regulators will need to consider the impact of noise on local communities and design airspace that minimizes the impact of UAM operations on the surrounding environment.

Researchers additionally identify whether the aircraft is a crewed aircraft or a UAS in the development of traffic management solutions for AAM (Borowiec, personal interview, 2023). When combining factors, the complexity of overlapping performance becomes clear in that there will be complexity in sharing rather congested airspace.

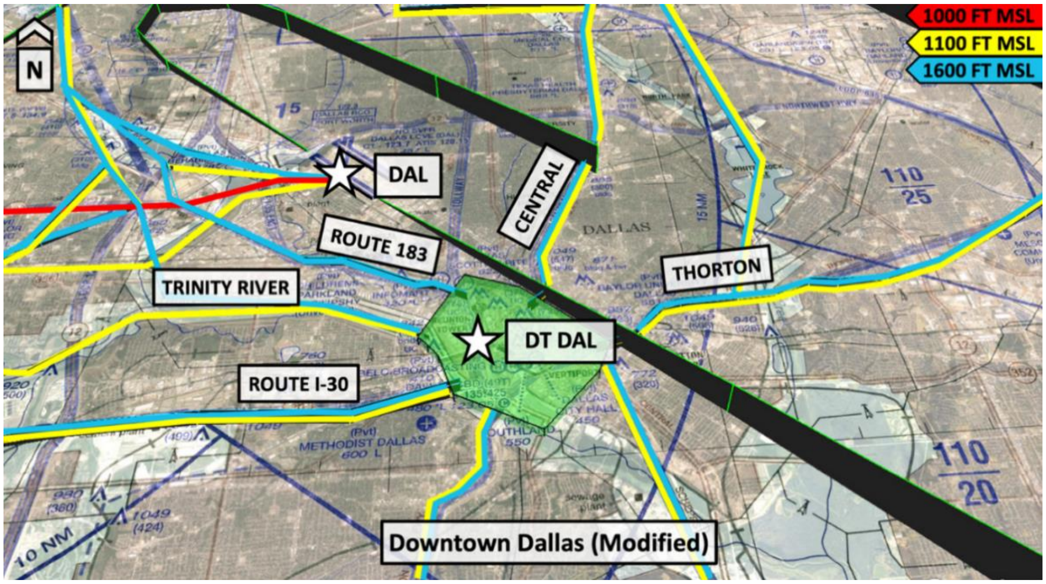
NASA Dallas - Fort Worth Case Study

Preliminary studies have been completed in specific test markets to identify early intra-urban corridor possibilities for AAM and how they would exist within the scope of the existing NAS. The NASA DFW Case Study's main objective is to evaluate the feasibility of various UAM traffic management concepts in the DFW metroplex. To achieve this objective, the authors developed several traffic management scenarios and tested them using computer simulations. Based on the simulations, the authors found that a UAM traffic management system that uses a combination of geofencing, dynamic airspace management, and automated conflict resolution can effectively manage UAM traffic in the DFW metroplex. The report also identifies several other challenges in need of addressing to implement an effective UAM traffic management system in the DFW metroplex including the integration of AAM operations with existing airspace users, the development of appropriate regulations and standards for UAM operations, and the need for a robust information-sharing infrastructure to support UTM (Keeler et al., 2021). The necessity for robust information sharing within the urban environment is echoed by other researchers due to the proximity of both AAM aircraft and traditional aircraft and rotorcraft operations (Borowiec, personal interview, 2023).

Interestingly the resulting corridors established by the study are collocated with transportation infrastructure through adaptation of existing FAA helicopter routing charts, which includes a provision that DFW International Airport and Dallas Love Field Airport operations will not be disrupted. To that end, the network of corridors finds itself coursing through major suburban areas of Dallas before returning radially inward toward Downtown Dallas. The study notes the need for a common frequency (UNICOM) in the urban core where congestion is greatest (Keeler et al., 2021). Concerns across multiple potential AAM-ready markets identify traffic volume and complexity in the urban core which is likely beyond the available workload of existing ATC due to task saturation

(Ramée, 2021). UTM is expected to provide services to aircraft to ensure safety and efficiency within the urban core, but it is important to note that because helicopter travel already exists in Downtown Dallas, the situation may be further complexified if traditional rotorcraft are not equipped to share a common information sharing protocol through UTM (Borowiec, personal interview, 2023). Because of this technological concern, the proposition for a UNICOM frequency in this core ensures that all aircraft are communicating location and intentions relative to one another. The issue still persists when considering small-scale UAS which may not be radio-equipped, but UTM is still under development and may yet address merging AAM with traditional air traffic in a shared urban environment.

Figure 6: Sample AAM corridors from NASA DFW case study



(Source: Keeler et al., 2021)

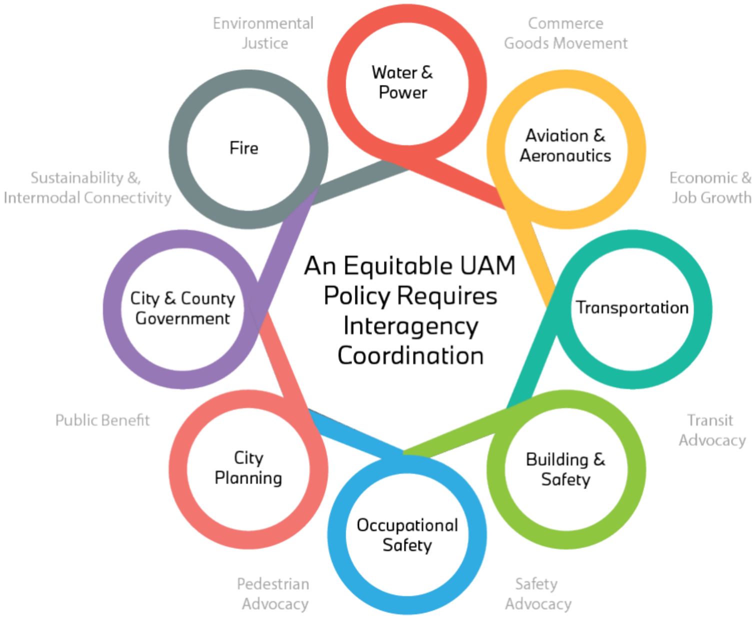
It is important to note that this study addresses strictly airspace concerns for the implementation of AAM corridors in the DFW area. In order to fully understand future corridor development, in the event that the corridors proposed were to be implemented into DFW’s urban airspace, it would certainly need to be coordinated with other agencies and communities that would be impacted or involved in the maintaining of a safe, efficient, sustainable, and equitable environment for AAM corridors.

Stakeholder Input and Priorities

Much of the technical documentation promoting the development of AAM and specifically AAM corridors focuses on conflicts with other existing air traffic within the NAS. It is however important to consider the externalities of AAM and other important factors which ultimately may dictate the course and purpose of AAM corridors. Interagency cooperation to cover issues such as safety, pollution, sound mitigation, and more topics is imperative to secure necessary community support and ensure equity for all users of AAM and those impacted by it.

Generally, eight sectors of governmental agencies may be involved in development of an equitable system for AAM (LADOT, 2021). Classification of agencies and interested parties for airspace and land based AAM infrastructure may be identified as seen in Figure 7 below.

Figure 7: Example of non-aviation stakeholders in the development of AAM



(Source: Los Angeles Department of Transportation, 2021)

Aviation comprises much of the technical airspace documentation and development related to the establishment of AAM corridors, but local government, emergency services, and transportation are all highly critical agencies in determining the feasibility of proposed AAM corridors. Furthermore, engaging with other groups seeking equity in the decision-making process may seek to further prove the environmental and economic sustainability of such developments. Researchers suggest wide reaching societal impacts of AAM in urban environments, which can include but are not limited to: perception of safety, security and privacy, as well as noise and visual pollution that can have wide ranging effects from decreasing property values to overall health (Bauranov et al., 2021). These issues, in conjunction with local jurisdictional regulations related to these issues, may have an overall impact on the establishment of AAM corridors and will be demonstrated in the case studies.

CHAPTER 3

METHODOLOGY

Introduction

This study utilized a qualitative approach to analyze the current regulatory status, momentum, and future needs for AAM corridors being integrated into the NAS. An in-depth interview was conducted with a relevant researcher in the field of aviation policy and development to understand the predicament which regulatory agencies at the state and federal level find themselves in with UAM and RAM manufacturers looking to begin commercial service within the decade with little codified on how this traffic will be managed. The in-depth interview can be found in Appendix C of this study. The framework for AAM corridor feasibility assessment developed from the interview and literature review (found in Appendices A and B) was then used to analyze three case studies of inter- and intra-urban AAM corridors.

Researcher Background and Biases

The primary researcher throughout the planning, conducting, and publishing of this study has been employed as an Aviation Planner. While the researcher’s employer does consult on vertiport development in partnership with a boutique aviation development firm, there is no present bias regarding professional conflicts of interest due to the researcher’s professional work pertaining to landside and airside planning, as opposed to airspace design or analysis, during the period of research. Similarly, the in-depth interview was performed by a similarly unbiased individual in the aviation planning space. Dr. Borowiec’s primary discussion pertained to experiences and analysis conducted during his time as a Senior Aviation Researcher at the Texas A&M Transportation Institute (TTI) working with state governmental agencies including the Texas Department of Transportation (TxDOT) with no commercial interest in the success of any AAM services or manufacturers.

Principal Assumptions of the Study

AAM is a subject that is still far from technological or operational maturity. Therefore, completing a theoretical case study of traffic management in a mature AAM environment requires certain assumptions to be made toward the development of the future of this space. The researcher made the following assumptions in the development of a framework to develop AAM corridors:

- UAM and RAM will be assumed to experience a significant enough demand to necessitate commercial crewed and uncrewed aircraft to be flown at regular intervals into, out of, and around the urban environment.
- Off-airport vertiports will be constructed at scale across metropolitan areas in both dense urban and less dense suburban areas to facilitate the movement of people to allow for last-mile transportation to be secured in a cost and time-effective manner.
- Regulatory aircraft standards for small UAS will reflect the requirement that all aircraft sharing low altitude congested urban airspace will be able to be identified by other aircraft or traffic management systems.
- Specific performance requirements will be established to address AAM aircraft carrying passengers.

- While a fully developed AAM infrastructure is in the research and development phase, this study assumes a fully built system, including establishment of AAM corridors.

Study Limitations

The primary researcher dedicated considerable effort to analyzing the policies of English-speaking countries, offering insights and further steps towards developing AAM in the United States and the United Kingdom. While the research highlighted agency efforts in developing AAM policies related to operations and traffic management, it is crucial to recognize that there may be additional perspectives and initiatives in other regions. In particular, the lack of consideration for the policy perspectives of potentially large AAM markets in Asia, such as Japan and Korea, is a notable gap. These countries have demonstrated significant interest and investment in the field of AAM, making their perspectives essential for a comprehensive analysis. To address this limitation, future studies could consider employing multilingual research methodologies to ensure a more comprehensive understanding of AAM policies worldwide. This expanded perspective will contribute to a better understanding of the global AAM landscape and facilitate the development of inclusive and effective policies that can shape the future of aerial mobility.

Without the use of comprehensive simulation tools, the case studies examined in this paper represent only hypothetical airspace design with simplified decision criteria. Because of the likely significant change to the volume of operations occurring within the urban environment, cities and metropolitan regulators would be shareholders with many unique concerns and demands which will need to be understood and in some situations compensated for. As with the introduction of metroplex airspace locations, such changes and optimizations to urban airspace are likely to need an environmental review due to the potential for externalities related to the introduction of more air traffic at lower altitudes.

Additionally, the creation of the framework for AAM airspace integration may not cover all issues present in the urban airspace environment in all locations. Unique population distributions, environmental concerns, or airspace restrictions may limit the development of high-volume corridors through areas that might otherwise have high demand for commercial AAM services.

Unique local economies and socioeconomics will additionally dictate unique demand patterns for commercial AAM services. While it may seem sensible to direct corridors between clusters of office and residential density, that may not necessarily reflect the nature of trip generation within a given urban area. As remote work becomes increasingly popular and many businesses move away from an urban core, concentrating AAM navigational infrastructure around the densest areas may not be the most effective use of resources or achieve the most prevalent efficiency gains. If within the densest areas of a city other modes of transportation are time-competitive and have a low cost per person per mile, then it may actually be suburban areas which see the greatest benefit in terms of travel time reduction for similar travel costs. If that is the case, then airspace designated for AAM should be catered to benefit efficient travel outside of the urban core and represent travel rotational around the urban center rather than radial from the suburbs to a dense core. This trend is difficult to generalize, however, and will not be symmetric in all directions, even within one city. Further studies seeking to identify likely AAM demand will be necessary on a per-market basis to determine what kind of behavior customers will likely display, which will influence design and placement of AAM corridors.

CHAPTER 4

RESULTS

Overall Framework Product

The resultant framework developed from the in-depth interview with Dr. Borowiec has been further strengthened by the current regulatory momentum for wide-scoped planning of AAM related-infrastructure. This comprehensive framework, outlined in Appendix A (for intra-urban corridors) and Appendix B (for inter-urban corridors) of the study, serves as a valuable tool for evaluating and analyzing various aspects of AAM infrastructure planning. To assess the practical application of the framework, three case studies were carefully selected. These case studies focus on inter- and intra-urban corridors, where the implementation of AAM systems has been proposed or studied. By examining these real-world scenarios, the framework's effectiveness in evaluating the feasibility, impact, and potential challenges of AAM infrastructure becomes evident.

The utilization of the framework allows for a systematic analysis of the proposed AAM corridors, considering factors such as airspace integration, land-use considerations, infrastructure requirements, and community engagement. By employing a structured approach, decision-makers and stakeholders gain valuable insights into the potential benefits and limitations associated with each case study. Through the application of this framework, policymakers and urban planners can make informed decisions regarding the implementation of AAM infrastructure, ensuring that it aligns with the overarching goals of transportation efficiency, sustainability, and safety. Furthermore, the framework facilitates a holistic perspective on AAM infrastructure planning, considering both the interconnectivity of urban centers and the potential impact on surrounding communities.

Its application in the analysis of inter- and intra-urban corridors enhances our understanding of the potential implications and benefits of integrating AAM systems into existing transportation networks.

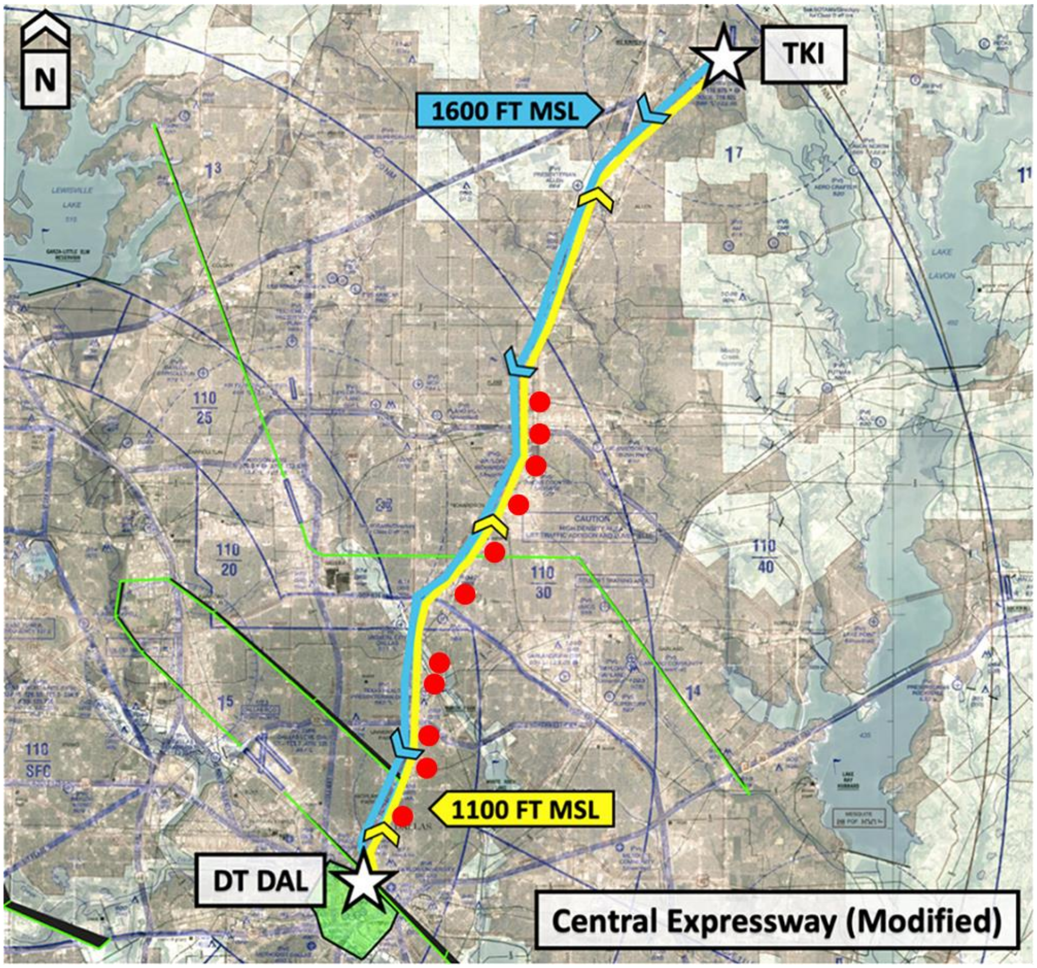
Reassessing Dallas - Fort Worth

The development of a framework for the evaluation of intra-urban AAM corridors can best be used to display how interagency stakeholder feedback may vary from a strictly aviation technical perspective. Returning to the literature that has already established a network of potential AAM corridors that are already clear of significant conflicts within the NAS allows for a planner's approach to understanding the environmental, economic, and accessibility concerns associated with the study.

As noted by existing research, multiple benefits may exist in the collocation of vertiport infrastructure and AAM airspace with existing transportation infrastructure, whether that be in the form of train stations, bus stops, or ride sharing hubs (Mendonca et al., 2022). The NASA DFW study ultimately had many AAM corridor options following major roadways throughout Dallas, similar to the published FAA Dallas helicopter routes (Keeler et al., 2021). One coincidental benefit to this approach that has wider planning and community engagement implications is that the State of Texas already has legislation for aviation noise abatement which dictates certain levels of assessment and action to mitigate sound pollution in the urban environment (Texas Department of Transportation, 2022). As noise abatement is also addressed by TxDOT and the Federal Highway Administration, the collocation of these intra-urban corridors over highways takes advantage of overlap in the responsibility for sound mitigation. In some cases, the right of way established to set back highways from residential areas and other sound mitigations from the built environment and AAM aircraft manufacturers may lead to harmonious collocation benefits when conducting the environmental assessment for an intra-urban network of AAM corridors.

Furthermore, the Dallas Area Rapid Transit rail lines often follow highways identified in the NASA DFW study, which is satisfactory to the assessment framework that emphasizes development of airspace and infrastructure that will serve to increase connectivity with other modes of transportation. Ultimately it will still be determined by developers, landowners, and regulatory agencies locally if vertiports will be collocated with points of increased potential such as transit stops; however, in a scenario with full AAM market maturity, the benefits of doing so and catering airspace to connect these locations in an efficient manner are clear.

Figure 8: Collocation sites



(Dallas Area Rapid Transit stations (red) along U.S. Highway 75 corridor overlay on top of McKinney to Downtown Dallas route proposed by Keeler et al., 2021)

DFW's geography has lent itself to the location of airports surrounding the urban core and networks of highways by generally connecting in a pattern similar to a spider web centered on the cities of Dallas and Fort Worth. As AAM does not explicitly need exclusive ground-based infrastructure, the opportunity to leverage the multitude of well-developed general aviation and commercial airports in areas absent of greenfield vertiport developments will facilitate integration into the DFW metroplex.

The use of existing airspace infrastructure is among one of the notable benefits of the DFW case study. The region has already conducted significant environmental research to identify concerns related to the metroplex airspace in DFW and received considerable community feedback in the original metroplex airspace environmental assessment (FAA, 2014). Given that environmental assessments can be a time-consuming process involving interagency partners, the use of existing systems such as the Dallas helicopter routes could simplify the assessment process because of similarities between the frequent operation of helicopters at low altitude and the proposed AAM operations. Altogether, this case study of the Dallas-Fort Worth metroplex should emphasize the complexity of decision making in regard to AAM airspace routing due challenges posed in an urban environment as well as proximity to multiple busy commercial and general aviation airports. The location of DFW International Airport with a north-south runway configuration creates some complexity in getting across an east-west axis of the metroplex due to the airport's central location between Dallas and Fort Worth. Love Field further complicates movement on the east side of the metroplex around the neighborhoods of west Dallas, creating only small channels between the two congested major airports for aircraft to pass. As discussed with Dr. Borowiec, much of the development of inter-urban corridors may rely on existing planned airspace infrastructure such as helicopter route charts with modifications being made at various altitudes to support routes branching off to other centers of interest for passenger demand.

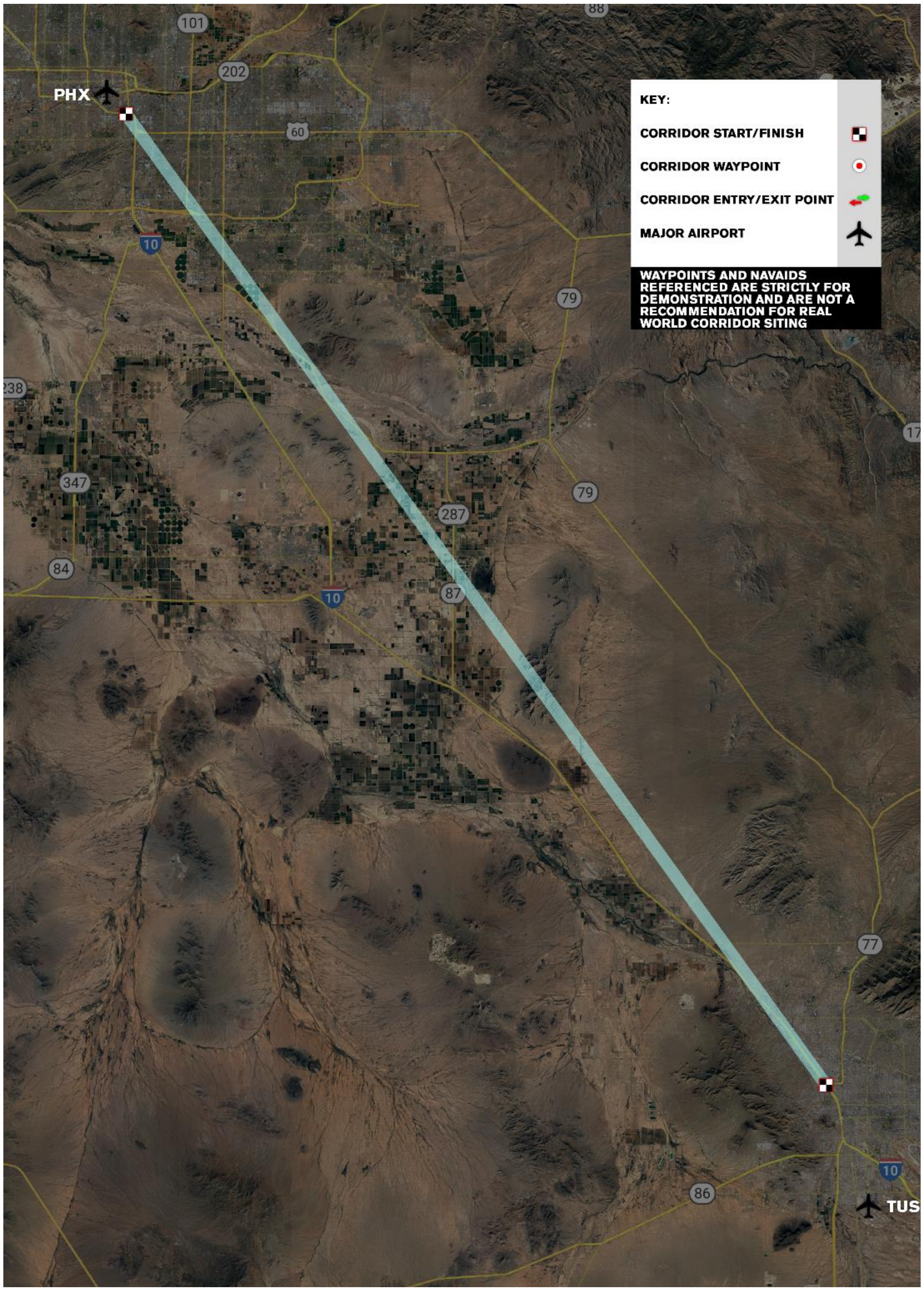
Phoenix - Tucson

The next case study relevant to simplified selection criteria involves creating an inter-urban AAM (Advanced Air Mobility) corridor. Unlike intra-urban corridors, which can be built upon existing airspace infrastructure such as NAVAIDs or published helicopter routings, inter-urban corridors have yet to be developed. Inter-urban corridors are expected to play a significant role in Regional Air Mobility (RAM) operations, particularly for shorter distance flights between metropolitan areas.

For this first analysis, the city pair chosen is Phoenix, Arizona and Tucson, Arizona. The combined statistical area (CSA) for the Phoenix-Mesa-Chandler metropolitan area comprises a population of 4,946,145 residents, while the Tucson-Nogales CSA has 1,099,913 residents (United States Census Bureau, 2022). When considering the statewide population of 7,276,316 within the same study, these two CSAs account for slightly over 83% of Arizona's entire population. The distance between Phoenix Sky Harbor International Airport (PHX) and Tucson International Airport (TUS) is approximately 110 miles, with a travel time by road of around 1 hour and 45 minutes. It is worth noting that neither city has a published FAA helicopter route chart in place.

A direct routing originating from PHX and terminating at TUS covers a total distance of 95.7 nautical miles and is the outright quickest possible corridor routing that connects the aviation hubs for each urban core. At a cruising speed between 125 and 150 knots unspecific to any eVTOL in development, this corridor would take approximately 40 minutes to travel from end to end. As is the case with all route options, the corridor in reality would begin just south of PHX and just north of TUS to ensure the corridor CEPs are not within controlled airport airspace.

Figure 9: Direct AAM Corridor Routing Between PHX and TUS

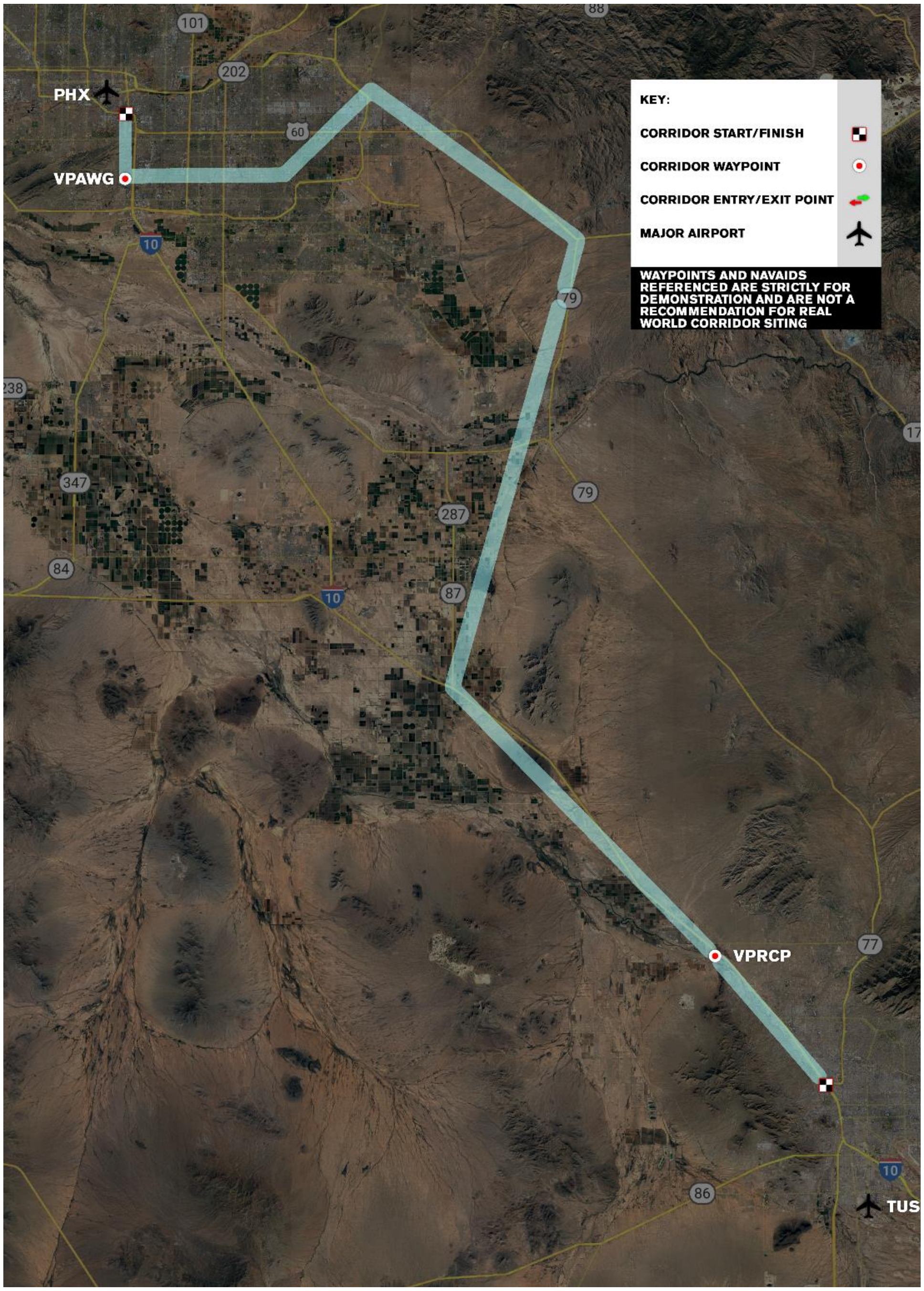


An AAM corridor routing which utilizes existing FAA navigational infrastructure to follow highway I-10 offers a multitude of benefits over the direct routing. The proposed routing would originate and terminate from the same CEPs just beyond controlled airspace outside of the international airports. While VFR reporting points are used as references to geographic locations for the corridor routings discussed in this the following case studies, it should be noted that they were included solely as reference points on aeronautical maps which planners or those involved in the interagency process would be able to see and understand. It is not an endorsement for the use of VFR reporting points as many AAM operations may not be appropriate for VFR operations as discussed earlier. From north to south, the route would travel to the VFR reporting point at the Ahwatukee Golf Course (VPAWG) and then Firebird Lake (VPFRB) at which point the aircraft would be at the southern extent of the Phoenix metro area. Both listed waypoints would likely be appropriate CEPs and offer AAM traffic the opportunity to branch off near the I-10, L-101, or US-60 highways to a final destination within the Phoenix metropolitan area. Continuing south, the route's next turn would occur at the Stanfield (TFD) VORTAC station. CEPs might be considered just north of this NAVAID to accommodate traffic traveling to the city of Maricopa or Ak-Chin Regional Airport. Continuing southwest the next waypoint on the corridor would coincide with the Rillito Cement Plant VFR reporting point (VPRCP), and finally directly towards TUS. If the TFD VORTAC serves as a CEP to access the City of Casa Grande, CEPs can additionally be located over Arizona City to provide access to Eloy followed by a CEP between the Pinal County Airport and the City of Marana to allow for departure towards the northern suburbs of Tucson. The total distance of the corridor would be 101.7 nautical miles (6.3% further than a direct corridor); however, travel time from end to end is only increased by about five minutes depending on the cruising speed. This routing never strays more than about seven miles from interstate I-10 while in the corridor and nearly follows the highway once in the urban environment, taking advantage of proximity to emergency resources and populations of potential commuters located between the two markets.

Figure 10: Corridor following I-10 between PHX and TUS

An alternative corridor that is neither direct nor follows interstate I-10 has been identified as a potential corridor candidate. Again, starting just off of the PHX Airport, this routing travels likewise to the Ahwatukee Golf Course VFR reporting point (VPAWG). This corridor differs from the others in that from this point it travels due east until crossing Val Vista Road, then heading northeast in order to avoid the controlled airspace of Chandler Municipal Airport, Mesa Falcon Field Airport, and Phoenix-Mesa Gateway Airport. While this does add considerable distance to the route, it does introduce the possibility for a CEP accessing the three main airports to service the aviation needs of the densely populated East Valley area. Aircraft capable of entering controlled airspace would be able to function similar to any other aircraft interacting with those airports. From here, the corridor would squeeze between the airport airspaces until crossing Ellsworth Road in Apache Junction and turning southeast towards Florence Junction where US-60 and highway 79 intersect. Although there is little development here other than a handful of dirt airstrips, a CEP in this location would provide an entry point for traffic coming from eastern cities such as Globe. The corridor would then return to follow I-10 around Eloy, potentially around the Picacho Peak VFR reporting point (VPCHO). Although a true alternative route avoiding I-10 might continue onwards to follow highway 79 to Oracle Junction and then down highway 77 into Tucson, relatively higher above ground level (AGL) altitude compared to the I-10 route, combined with the scorching heat of Arizona summers guarantees high density altitudes along this route which may be performance limiting for some AAM platforms, which are being designed for an assumed much lower level of flight. To remedy this situation, Tucson could implement an intra-urban corridor towards Oracle Junction from Downtown Tucson if appropriate demand existed. The total distance of this alternative corridor is 121.1 nautical miles (26.5% further than a direct route and 19.1% greater than the I-10 mimicking route) and would take approximately 55 minutes to travel from end to end. This route does lose what the I-10 route gains in the form of proximity to emergency services located in towns along I-10. One benefit of this route is that it entirely avoids the Coolidge and Casa Grande areas, which feature significant flight training operations that might otherwise interfere with efficient travel.

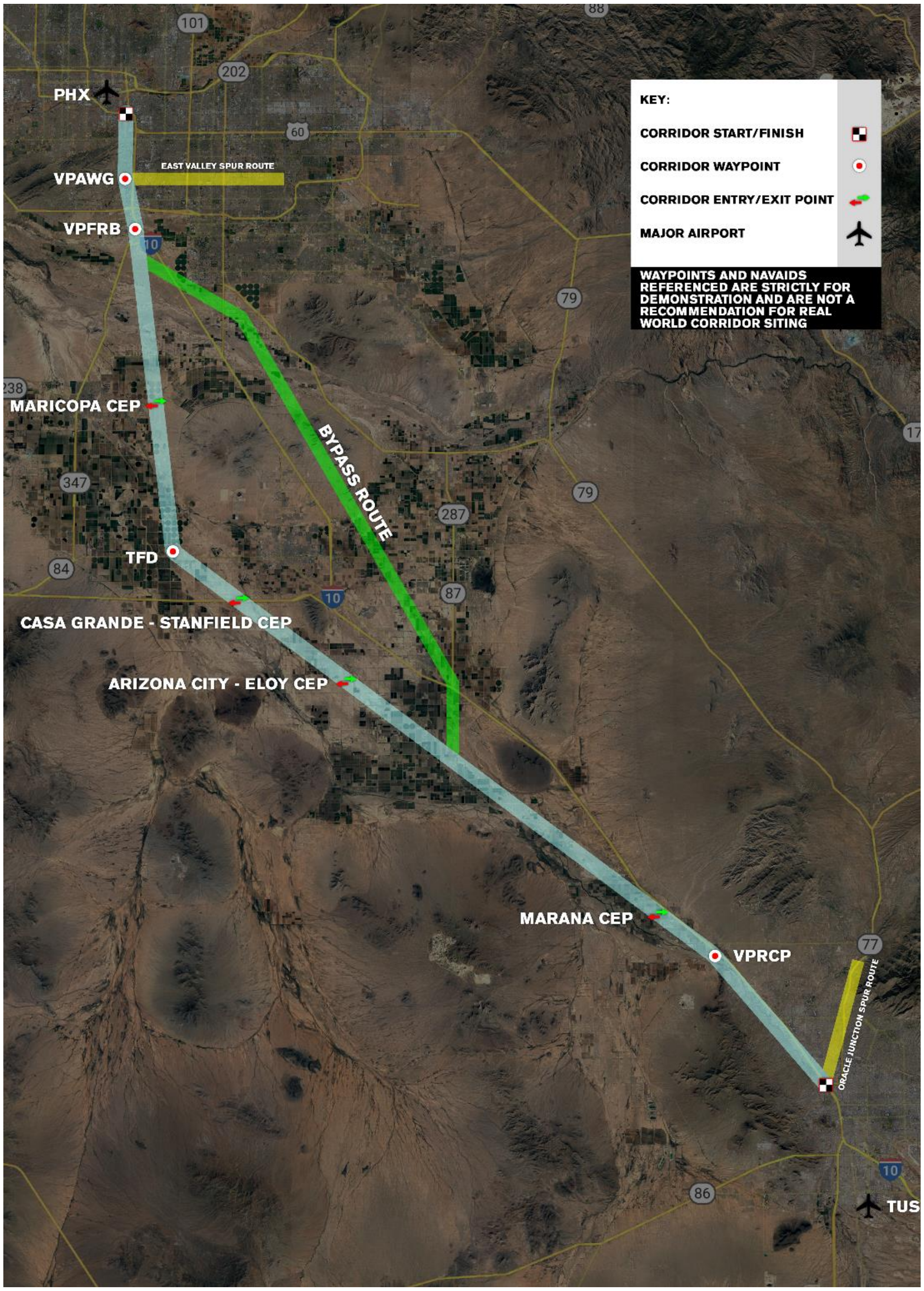
Figure 11: Eastward Diversion Routing Between PHX and TUS



WAYPOINTS AND NAVAIDS REFERENCED ARE STRICTLY FOR DEMONSTRATION AND ARE NOT A RECOMMENDATION FOR REAL WORLD CORRIDOR SITING

The recommended primary AAM corridor given the basic framework for evaluation in this case would be the route following U.S. Interstate I-10 from Tempe all the way through to Downtown Tucson. The main corridor entry and exit points (CEPs) lie just under the veil of controlled airspace to allow self-maneuvering to a final location, or if desired, enter airspace controlled by ATC in order to land at either PHX or TUS. CEPs along the middle of the corridor allow for intermediate city stops or reroutes in proximity to cities in between Phoenix and Tucson, including Casa Grande, Eloy, Picacho, and Marana (north to south direction of travel). The alternate option does provide significant value to the inter-urban system if both were to be implemented by allowing for traffic to diverge east and access the East Valley of Phoenix with Chandler, Gilbert, and Mesa as likely destinations, or Oracle Junction and Oro Valley in proximity to Tucson. Not only does this provide more direct routing in some instances, although likely with less traffic than the preferred corridor, UTM DCB may be applied to alleviate congestion along consecutive CEPs along Interstate I-10 during peak hours.

Figure 12: Preferred AAM corridor routing between PHX and TUS



The framework for evaluating AAM corridor siting performed as expected with the resultant preferred option becoming a blend of a direct path that has been slightly adjusted to cover intermediate destinations. What was identified in this case study is that while an alternative corridor may not entirely satisfy selection criteria, traffic management tools may be applied in route segments in the event of corridor congestion without jeopardizing the benefits of having a standardized routing for AAM traffic between urban cores.

Seattle - Portland

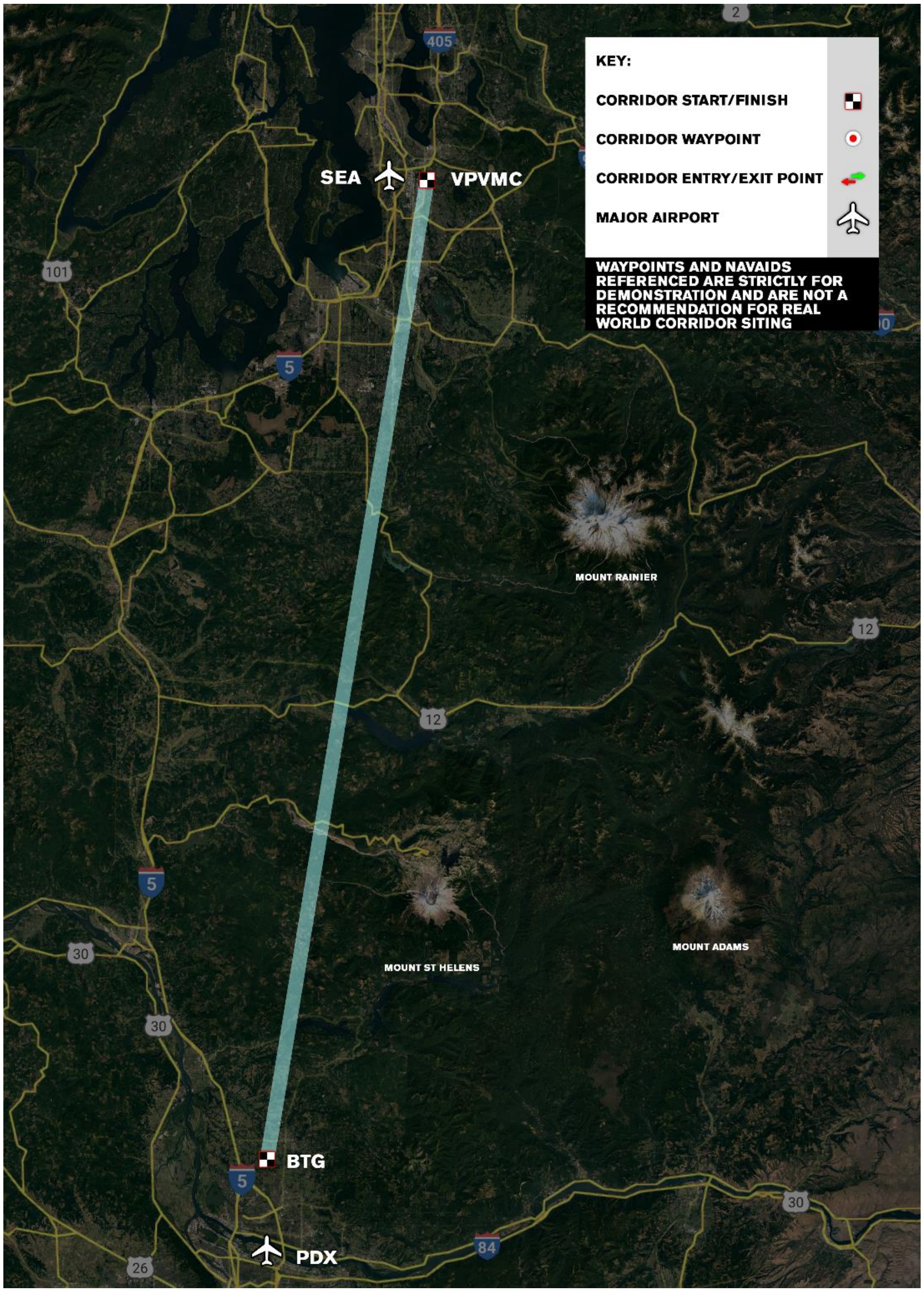
The next case study focuses on another potential inter-urban AAM corridor that features similar features conducive to corridor establishment along a set path. Seattle, Washington and Portland, Oregon account for the two largest cities in the Pacific Northwest of the United States. With a combined population of 8,238,344 residents between the Seattle-Tacoma CSA and the Portland-Vancouver-Salem CSA, this area (similar to Phoenix and Tucson) accounts for much of the surrounding region's population and economic activity (United States Census Bureau, 2022). Seattle-Tacoma International Airport (SEA) and Portland International Airport (PDX) are 129 miles apart directly and about two and a half hours by road, highlighting an opportunity for AAM and RAM to significantly cut commuting times between the two major metropolitan areas.

As with the Phoenix - Tucson case study, the creation of an inter-urban AAM corridor between Seattle and Portland is simplified in part thanks to the presence of an interstate, namely Interstate 5, on a relatively direct path between the two centers of population. This interstate provides a convenient and established transportation route that can be leveraged for the development of the AAM corridor. The corridor would enable efficient and seamless transportation options for the residents of Seattle and Portland, facilitating travel and connectivity between these two major cities. The interstate route additionally offers several advantages for the implementation of the AAM corridor. Firstly, it provides a clear and straightforward pathway that can be utilized for the deployment of AAM infrastructure, such as vertiports located on airports or purpose-built. This simplifies the planning and construction process, as the existing interstate alignment can serve as a guideline for the corridor's aerial infrastructure. Additionally, the presence of multiple intermediate stops along the route further enhances the viability of the inter-urban AAM corridor. These stops are strategically located in cities with adequate aviation infrastructure, including well-equipped airports or other aviation facilities. Such infrastructure supports the efficient operation of AAM vehicles and enables convenient commuting in either direction between Seattle and Portland. The availability of intermediate stops also enhances the corridor's accessibility, allowing travelers to conveniently reach destinations with larger spheres of population density. Capitalizing on the existing interstate and leveraging the aviation infrastructure in the intermediate cities, the inter-urban AAM corridor between Seattle and Portland can provide a seamless and time-efficient transportation option to increase connectivity.

Among the reasons to collocate the AAM corridor along Interstate 5 is the recognition that the region where it is being proposed is highly conscious of and sensitive to the environmental impacts associated with infrastructure developments. By choosing to collocate the AAM corridor on I-5, it presents several advantages, with one of the most significant being that I-5 already possesses an established right-of-way that is clear from natural forests and areas of residential density. This decision to utilize I-5 for the AAM corridor takes into account the environmental considerations that are crucial in this particular region. The local community has expressed concerns regarding the potential ecological consequences that large-scale infrastructure projects can have, making it essential to minimize any detrimental effects. By leveraging the existing infrastructure provided by I-5, the need for clearing additional natural forests or encroaching upon areas with higher residential population density can be mitigated. The presence of an established right-of-way along I-5 offers a valuable advantage for the collocation of the AAM corridor. This existing clear path allows for the efficient integration of the new infrastructure within the existing transportation network, reducing the need for extensive land acquisition or disruption to the surrounding environment. Utilizing this pre-established right-of-way eliminates the necessity of additional land-use changes and potential conflicts with ecologically sensitive areas or densely populated residential zones. Moreover, by collocating the AAM corridor along I-5, there is an opportunity to leverage the existing infrastructure, such as bridges, interchanges, and access roads. This allows for better integration of the AAM system into the transportation network, enabling seamless connectivity and enhancing overall efficiency.

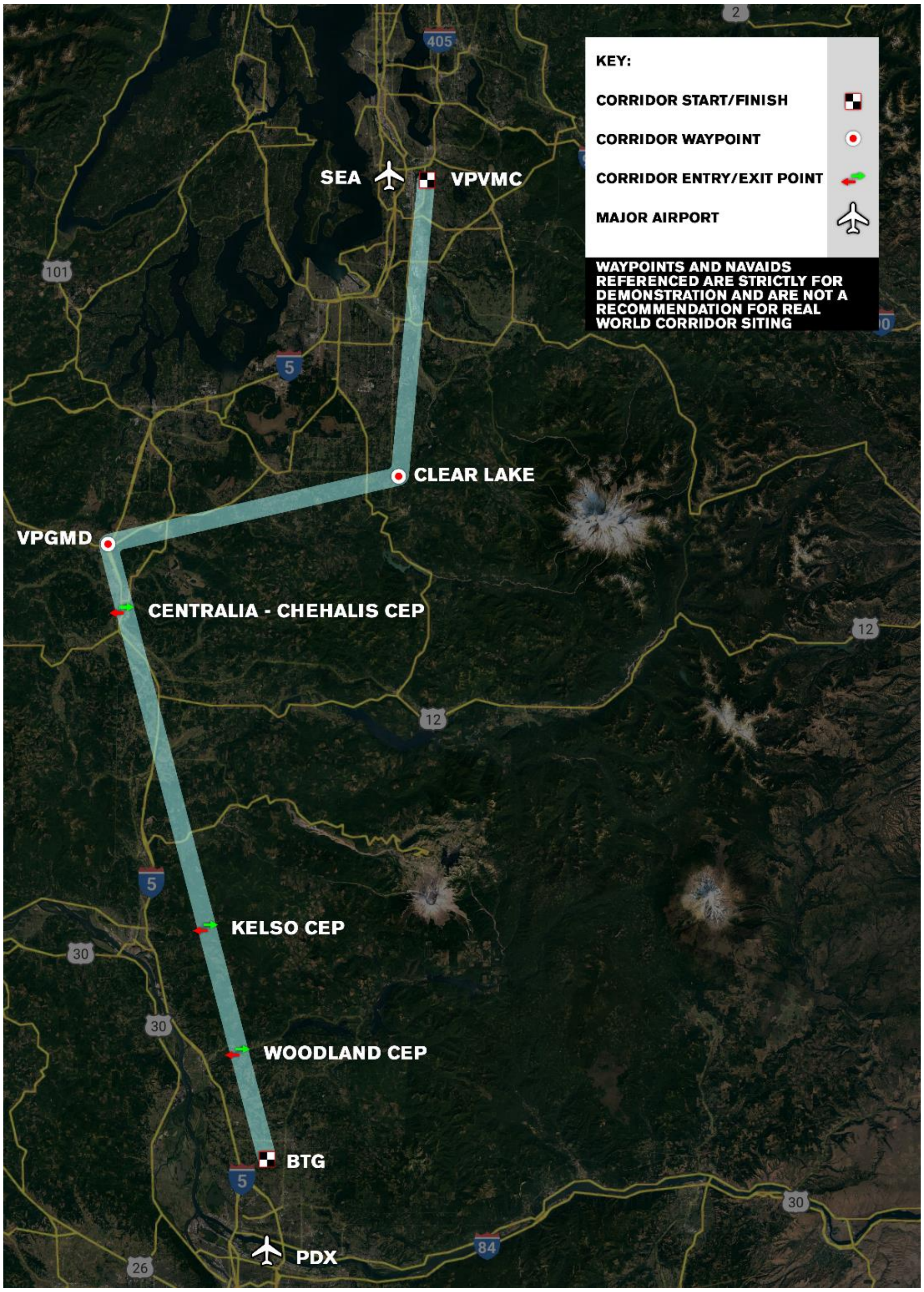
Because of the necessity to include access to the urban core of Seattle, even the direct routing is a perfectly straight line. In this proposed corridor, AAM traffic departing SEA would travel east to clear conflict with SEA airspace just south of Renton Municipal Airport at the Valley Medical Center VFR reporting point (VPVMC) where the originating CEP for the corridor would be located. From there, the route would continue all the way to Portland, terminating at the Battle Ground (BTG) VORTAC radio navigational aid which lies just north of PDX and its controlled environment. Without any other geographic or environmental considerations, this corridor would total 116.5 nautical miles in distance and take approximately 50 minutes to travel between the two extents of the corridor. While other routing proposals may feature considerable increases in total distance and travel times, it is important to note that this corridor is not a viable plan for the implementation of an AAM corridor due to geographic features of the region, particularly the presence of large elevation changes between Mount Rainier and Mount Saint Helens. Given that most proposed AAM aircraft are designed for low-altitude flight, routing the corridor through terrain that experiences elevations up to above 4,000 feet in meteorological conditions that are often less than suitable for VFR, and considering the lack of intermediate population centers along the route, a determination may be made that an alternate route may be more feasible and appropriate for AAM operations.

Figure 13: Direct AAM corridor routing between SEA and PDX



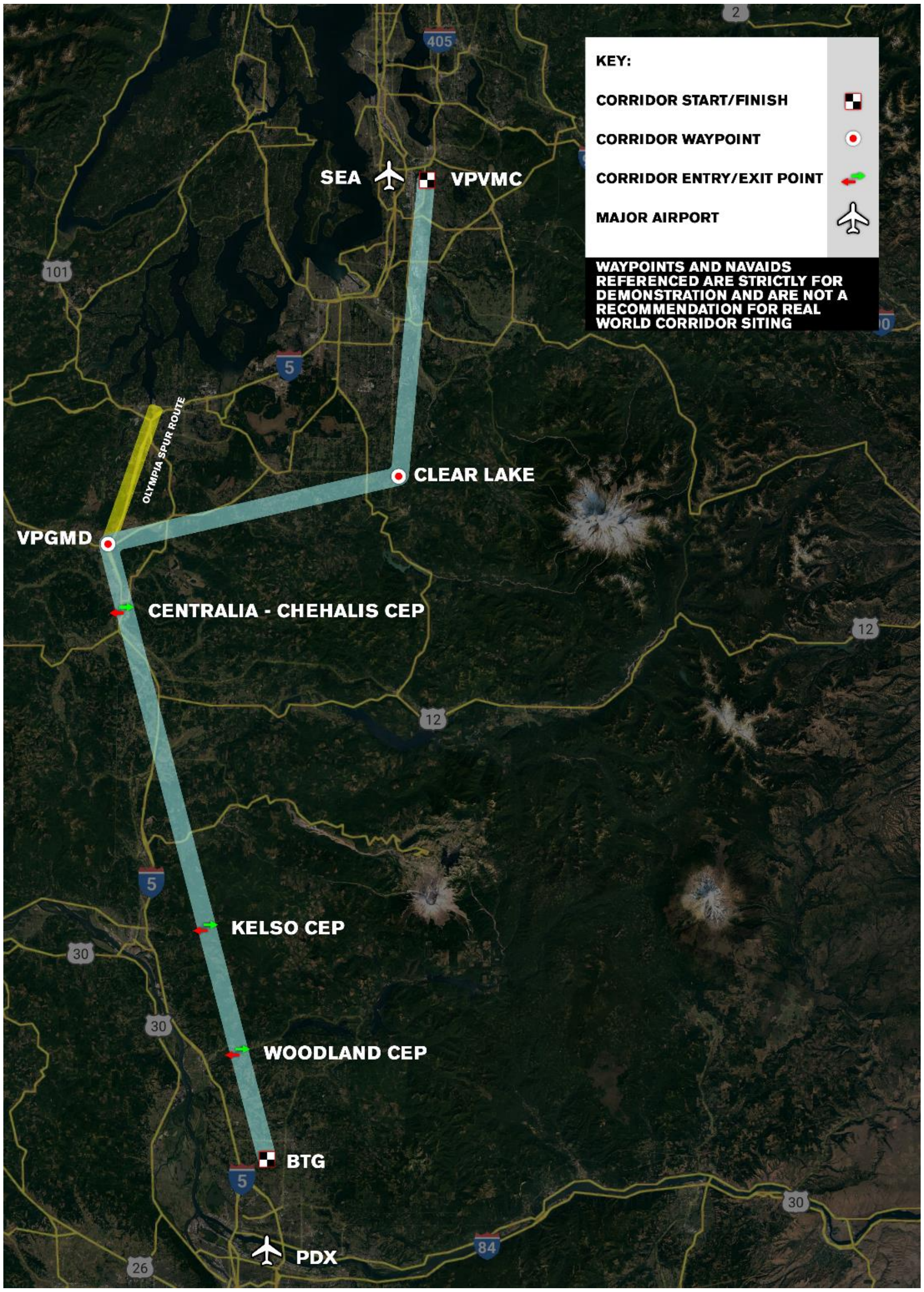
Hailing from the previous commentary on the benefits of corridor collocation with Interstate 5, the primary route follows a similar design strategy to that of the I-10-mimicking routing in the PHX-TUS case study. From the CEP at the waypoint VPVMC, aircraft would transit south until crossing Clear Lake. Although the logic of following the interstate for best commercial corridor use might seem clear, airspace between Tacoma, Olympia, and Joint Base Lewis-McChord is highly congested and presents no corridor for UTM operations without needing complex redesign of the airspace between the adjacent airports. The restriction at Clear Lake is additionally necessary to keep AAM traffic clear of the Rainier Military Operation Area which is utilized by military aviation for conducting drills and is largely incompatible with the purpose of AAM operations of any kind. From Clear Lake, the route would rejoin I-5 from Grand Mound, WA at the VFR reporting point Grand Mound (VPGMD). From there, traffic would then proceed direct to the BTG VORTAC which is the terminating location of the corridor heading southbound. Along this corridor, CEPs can be located between Chehalis and Centralia, WA, and as the corridor approaches Kelso, WA and Woodland, WA. The corridor strays as far as 25 miles from the interstate; however, heading south from a CEP located at Grand Mound would see a deviation from I-5 of no more than 5 miles. The total distance of this primary corridor would be 140 nautical miles (20.2% longer than the direct corridor) and takes approximately one hour to travel from SEA to PDX, cutting nearly an hour and a half travel time compared to driving.

Figure 14: Corridor Following I-5 Between SEA and PDX



While the I-5 AAM corridor option provides the highest level of connectivity and resources to support AAM operations, the recommended corridor plan for SEA-PDX does incorporate lessons learned from the PHX-TUS case study in the utilization of bypass corridors around areas with consecutive CEPs. The Seattle to Portland corridor is even longer in distance than that of the previous case study. Ensuring efficiency through bypass corridors offers even greater benefit to the UTM ecosystem considering how closely interconnected the two metro areas are. Relevant to the airspace complexities of Tacoma, Olympia, and Joint Base Lewis-McChord, the preferred AAM corridor evaluation includes a spur off of the primary corridor from Grand Mound, WA up towards Olympia, WA. The addition of this spur increases accessibility from the Washington State capital city, which is a major consideration in the regional transportation plan for travel between Seattle and Portland.

Figure 15: Preferred AAM corridor routing between SEA and PDX



The Seattle - Portland AAM corridor feasibility study highlights how geographic challenges as well as the existing NAS structure may require modifications to a simple collocation methodology. The benefits of remaining in proximity to centers of population and industry, however, should not be considered less than imperative as reflected in the inter-urban AAM corridor framework emphasizing collocation as a method to mitigate environmental, safety, and transportation accessibility concerns that arise when approaching airspace planning from an interagency approach.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

Significant Findings

Before analyzing the findings of the mock corridor analysis, it is imperative to reiterate that AAM and its associated inclusion in the NAS still requires significant scoping and development on many fronts (including but not limited to shared use airspace, rules of flight operation, i.e., IFR/VFR or [to-be-developed] DFR, and required equipment to participate in particular classes of airspace).

From the case studies of inter-urban AAM corridors, one of the most significant findings is that routings which collocate with existing interstate highways benefit from direct or improved access to intermediate city airports and vertiports, see increased risk mitigation in the form of accessibility to emergency response services, and increased access to clusters of population and business relevant to the services provided by AAM. In these studies, geographic features as well as population distribution between two metro areas prevent a direct routing between international airports from being the preferred option for an AAM corridor because of the necessity of having CEPs near originating and terminating vertiports. Planning includes the emphasis on equity in the development of AAM corridors through collaboration and involvement of local stakeholders while also articulating the benefit of accessibility to enhanced transportation services in exchange for the externalities associated with AAM overflight of urban areas.

Secondary corridors either independent from primary inter-urban corridors or bypassing areas with a multitude of CEPs as discussed in the inter-urban cases may additionally provide relief to UTM services through DCB during peak traffic. The obvious benefit of doing so is that goods or passengers can flow around traffic which may be slowing or congesting at intermediate points along the primary AAM corridor. If CEPs can be considered entrance and exit ramps to a theoretical highway in the sky, then secondary corridors provide tools for UTM to (in continuing the analogy) create segregated HOV bypass lanes that prioritize traffic with the intent of continuing along the full distance of the corridor or highway.

An important takeaway from this simulated corridor siting analysis is the beginning assumption that AAM has reached a level of maturity which necessitates corridors independent of existing airspaces in the NAS. The near-term solution for implementing AAM will likely not be precisely as described. Initially, existing procedures will be applied; traditional navigational aids will have a role; and some interactions with air traffic controllers will continue until technology improves and demand for AAM and associated services builds to a greater extent. Once a clearer picture is gained as to the performance capabilities of participating aircraft, technologies, and operational and business goals of AAM operators, regulators will have greater insight into how to create a safe and effective system to manage and successfully integrate AAM into the broader NAS. Ongoing testing of AAM-craft will offer early insights, but change will be likely over time as the market matures. Regardless of the details in how AAM is handled in respect to corridor technical policy, the importance of interagency planning and engagement in long-term corridor siting studies seen in the simulated case studies in this paper is still relevant to the customer and the communities impacted by the presence of AAM in the skies above.

One of the major items of note for the inclusion of AAM in the NAS is the need for structure regarding small commercial UAS. As noted by Dr. Borowiec, commercial drone operators have a vested interest at the moment to maintain a currently disorganized and uncontrolled environment which allows for much greater freedom of movement and operation within the present set of regulations. In the present-day environment without full-sized UAM and RAM aircraft operating, drone services provide little threat to other aviation activities given most regulation is addressed to limiting interactions between UAS and traditional airspaces of the NAS. This level of operator autonomy must be addressed as more commercial uses for drone technologies become present, and competition for airspace as low-altitude UAM and AAM operations increases in airspace below what is traditionally used for commercial service. Among the complexities in finding a common regulatory framework to cover all forms of AAM and depending on the particular performance targets established by individual operators, some stakeholders may be resistant to participating in the planning and development processes, while others may be disappointed if they are left out.

Recommendations

Further analysis on the optimization of inter-urban trips will be needed in order to determine the strategy for designing standardized routings based on traffic demand, accounting for existing air traffic such as helicopters, commercial jets, or general aviation operating environments, and other considerations such as sound propagation and local geography within the built environment. To do so, complex simulation tools will be necessary to evaluate all of these factors. Modern GIS software may be capable of providing such analysis; however, this fell beyond the scope of this research as it was simply focused on outlining a catch-all guideline for aviation system planners and air traffic managers to develop AAM-friendly airspace around the existing NAS infrastructure.

As previously noted in this narrative, collocation with other modes of transportation will aid the last mile trip planning problem. While many various market factors will ultimately dictate where vertiports are built within the urban environment, it is important to consider that collocation of AAM routings may also benefit the integration of new technologies into the NAS. Noted in the potential corridor criteria is that existing transportation infrastructure has already been analyzed for its environmental impact on the region and collocating along highways, train lines, and other city features that are separate from dense business and residential areas provides a ground-level space below AAM corridors with less risk factors when flying at relatively low altitudes that will be utilized by these commercial services. While new AAM corridors will almost certainly necessitate an Environmental Assessment as part of the NEPA review process (if not an entire environmental review necessitating an Environmental Impact Statement), this framework should be used to encourage planning efforts which leverage the findings of previous environmental studies to make informed siting decisions which are conscious of previous planning efforts and community input regarding similar issues with the goal of eliminating proposals which may be determined to have local environmental impact deficiencies already identified in earlier projects.

A final recommendation for the inter-urban AAM corridor evaluation process includes the design of bypass or congestion relief paths where UTM will be able to direct continuing traffic away from areas along the primary corridor that may have increased activity along consecutive CEPs. This may not be feasible in all scenarios as some corridors may exist as the sole direct routing in avoidance of conflicting airspaces. Nonetheless, this has been added to the framework of Appendix B for inter-urban AAM corridors to reflect an additional tool for traffic management through the inclusion of alternate paths, in addition to the availability of multiple altitudes discussed in performance-based separation of AAM aircraft.

CHAPTER 6

CONCLUSION

Contributions

Numerous individuals have contributed to the success of the development of this framework. Primarily among those is Jeff Borowiec, Ph.D. who offered plentiful insight into how discussions at the statewide policy level were led by advanced air mobility stakeholders and their varying opinions on strategies for organizing the next generation of the National Airspace System featuring emerging technologies and services. Direction towards Texas Department of Transportation Urban Air Mobility Advisory Committee aided significantly in the consideration of smaller UAS operators and how not all commercial operations within the airspace will benefit from a centralized management of aircraft beyond what is available today. Furthermore, discussing what a controlled environment for UASs and other AAM aircraft would look like led to greater research into delineating between which operations will be maintained in a positive control environment and which will not. Lastly, with variety in terms of aircraft size, crew, purpose, and performance from new entrants into the AAM space, there is a worthwhile conversation to be had on how policy can be developed to ensure operational efficiency and whether that includes segregating classes of AAM traffic to allow like aircraft to operate within specific windows apart from impeding traffic. Commentary within this thesis provides why that may be a slippery slope that is unattainable given precedent set by the existing structure of the NAS; however, Dr. Borowiec and the researcher discussed what benefits may exist in that theory and why operators may or may not support that form of structure in an AAM-friendly NAS.

The Transportation Research Board Aviation Group 2022 mid-year meetings were another source of inspiration for this research. In the Joint Meeting of Aviation Administration and Policy (AV010) and Aviation System Planning (AV020), Kevin Antcliff of X-Wing and formerly of NASA discussed his perspective of RAM as it applied to his co-authored NASA whitepaper and how his commercial manufacturer was working to bring autonomy into the AAM space for various applications. The discussion offered insight into the commercial applicability and promise of RAM as well as the role of autonomy within the management of future commercial aviation services.

Closing

AAM is a concept for a new form of aerial transportation that holds great potential for significantly enhancing connectivity and reducing transit times within the urban environment. However, it is important to note that this technology is still in the process of being developed and certified by regulators for safe and reliable commercial passenger service. While the promise of AAM is encouraging, it remains largely unproven to the flying public at this stage. Considering the uncertainties surrounding the success and demand for launch markets of UAM services, it would not be surprising to witness a shift in focus towards RAM services, particularly in the domains of delivery and logistics. If the uptake of UAM services falls short of expectations or proves unsuccessful, the industry may see a greater emphasis on the development of RAM services to meet the evolving demands of transportation. In such a scenario, the development of the NAS would likely undergo some adjustments to accommodate this shift in AAM's direction. Rather than prioritizing the creation of infrastructure for intra-urban corridors that facilitate UAM passenger services, there would be a reevaluation of priorities. The focus would likely be redirected towards inter-urban corridors, which would serve as crucial routes for RAM operations and contribute to the efficient movement of goods and services between regions.

Regardless of the success of UAM within the AAM market mix, it is undeniable that the expansion of UAS operations will require the implementation of a traffic management structure. As the utilization of drones for various commercial applications continues to rise, the lower-level airspace is becoming increasingly congested. Recognizing this need, the FAA is actively involved in the development of a traffic management system, focusing on the concept of UTM. Moreover, the International Civil Aviation Organization (ICAO) is also collaborating with international partners to address this issue and has published literature related to UTM. These efforts from both the FAA and the ICAO highlight the significance of establishing an effective UTM framework to ensure the safe and efficient integration of UAS into the NAS under the umbrella of AAM.

The AAM corridor identification and evaluation framework presented in this study is intended to be used as a preliminary tool for studying suitable inter- or intra-urban AAM corridors. However, it is crucial to note that this framework should not be considered a comprehensive planning solution for all scenarios. Urban environments possess unique characteristics that are shaped by various stakeholder inputs and community-specific needs. Recognizing the importance of equity in urban and transportation planning, it becomes essential to involve stakeholders at all levels of the local, regional, and higher agencies in the scoping and evaluation processes before establishing corridors. Considering the transportation networks and externalities associated with low altitude flying over densely populated areas, such as sound and potential pollution, it is crucial to ensure comprehensive evaluation and inclusive decision-making. Therefore, the participation of stakeholders becomes paramount in order to strike a balance between meeting transportation demands and addressing the concerns and interests of the community. While the AAM corridor identification and evaluation framework can provide valuable insights in the preliminary stages, it is imperative to engage with stakeholders and conduct thorough evaluations to ensure that the establishment of corridors aligns with the values of equity and addresses potential impacts on the urban environment and its inhabitants.

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APPENDIX A

INTRA-URBAN AAM CORRIDOR FEASIBILITY FRAMEWORK

Intra-Urban AAM Corridor Feasibility Framework

Guide for airspace planning concerning advanced air mobility with interagency stakeholder considerations

Task Category	Evaluation Criteria	Planning Response
Considerations for Aeronautical Integration	Corridor(s) does not intersect any Special Use Airspace. (See 14 CFR Part 73 and Aeronautical Information Manual Chapter 3 Section 4)	*Avoidance of Special Use Airspace ensures that AAM operations are not presenting conflict to areas of airspace that are either prohibited, resricted, or hazardous to nonauthorized aircraft.*
	Corridor (s) does not intersect with Class B, Class C, or Class D airspace at published corridor altitude.	*In order to avoid unneccesary conflict with controlled airspace and increase controller workload, corridors should navigate around these airspaces whenever possible. Class B, Class C, and Class D airspaces are depitced on Section and Terminal aeronautical charts.*
	Corridor(s) do not create conflict with existing airport procedures or impede access to existing aeronautical infrastructure.	*Ensure that access to aeronautical facilities within the present-day NAS is not jeopardized. Attention should be given to published airport departure and arrival procedures as well as airspace protected by 14 CFR Part 77 at all airports and heliports.*
	Corridor(s) (where possible) makes use of existing navigational infrastructure.	*NextGen innovations may not necessitate the use of radio based navigation like VOR however many existing airways have already been evaluated for the effects of air traffic, potentially similifying the analysis of airspace impacts.*
Supporting the AAM Business Case	Bypass corridors are analyzed to ensure traffic along consecutive CEPs does not cause unncessary travel time increases.	*Similar to the previous criteria discussing cost competitiveness, if the service is not time competitve due to congestion along the corridor service adoption may be limited.*
	Corridor(s) serve existing transportation demand radially towards and axially around the urban core.	*As suburban areas now feature more business activity and intra-suburban travel cuts some demand for travel to a dense central urban core, corridors will need to reflect that not all passengers or goods will move radially but rather a combination of both radial and axial trips. Additional studies of this may be required beyond available data of congestion and vehicle miles travelled data.*
	Routing of corridor(s) does not create issues of last-mile transportation by leaving passengers far from access to other forms of transport.	*Collocation opportunities with public transit, ridesharing, and park-and-ride facilities should be identified.*
	Corridor siting entering a large city follows a somewhat centralized path to limit excessive travel to and from the corridor to an aircraft final destination.	*Collocation with highways as demonstrated in the case studies generally supports this behavior, but a study into the location of vertiports within the city specific to the corridor location in discussion will produce best results.*
	Corridor(s) do not encourage flight over areas where the urban environment introduces hazards when flying at low-altitude.	*Examples may include:* *Central business distric areas with skyscraper buildings*

Geographic and Environmental Considerations	Corridor(s) are not sited for the mitigation of externalities in areas that would raise concern of Environmental Justice.	*In most cases this would require a NEPA review prior to the implementation of the corridor, but effort needs to be made that the path of a corridor does not unjustly and disproportionately impact a group of individuals.*
	Corridor availability allows for DCB to manage a balanced volume of traffic.	*Continuing from the previous critera, the availability of mutliple corridors along similar axis within the urban enviroment allow for balanced traffic as opposed to extreme amounts of traffic procuding externalities such as sound over a singular area.*
	Corridor(s) do not encourage flight over areas that woud cause significant impact to wildlife or natural resource preservation.	*This criteria is aimed at identifying areas that would be at risk of necessitating a full environmental assessment.* *Areas to consider may include national parks, wildlife refuges, and wilderness areas which are often identified on sectional aeronautical charts. Protected environment inventories from state and federal sources should also be identified.*
Interagency and Community Engagement	Identifty stakeholders in other forms of transportation that will be supportive of AAM.	*To solve last-mile transportation from the airport or vertiport to the user's final destination, stakeholder from ridesharing, public transportation, parking, and paratransit entities will be critical to support the business viability of AAM in the urban environment.*
	Identify agencies and entities at all levels (city, regional, state, federal) which may be impacted by externalities associated with AAM operations.	*Examples may include:* *Transportation departments to address traffic created at local vertiports* *Local emergency services to develop response plans* *Economic development commissions which may benefit from access to intermediate cities.* *See Figure 2 from Mendonca et al., 2022 for additional regulatory considerations*
	Identify advocacy groups relevant to areas impacted or local issues presented in the planning process.	*Examples may include:* *Neighborhood advocacy in areas that may see significantly increased noise overhead* *Environmental protection and preservation groups* *Local pilot associations* *Many federal agencies and state-level depatments of transportation have published public involvement toolkits to assist in stakeholder and community engagement.*

	Identify relevant regulation that may impact corridor siting and development.	*Examples may include:* *Noise ordinances* *Zoning requirements to consider siting over compatible land uses* *Protected environment inventories*

APPENDIX B

INTER-URBAN AAM CORRIDOR FEASIBILITY FRAMEWORK

Inter-Urban AAM Corridor Feasibility Framework

Guide for airspace planning concerning advanced air mobility with interagency stakeholder considerations

Task Category	Evaluation Criteria	Planning Response
Considerations for Aeronautical Integration	Corridor originates and terminates within reasonable proximity of one or more commercial service airports.	*List commercial service airports within range of the corridor's start and finish to support operations with passengers transitioning from airline service to AAM.*
	Corridor passes intermediate airports.	*List airports, heliports, and vertiports within reasonable proximity of the middle segments of the route which could be used or adapted to support refueling/recharging, enplanement, and other AAM-related activities.*
	Corridor does not intersect any Special Use Airspace. (See 14 CFR Part 73 and Aeronautical Information Manual Chapter 3 Section 4)	*Avoidance of Special Use Airspace ensures that AAM operations are not presenting conflict to areas of airspace that are either prohibited, resricted, or hazardous to nonauthorized aircraft.*
	Corridor does not intersect with Class B, Class C, or Class D airspace at published corridor altitude.	*In order to avoid unneccesary conflict with controlled airspace and increase controller workload, corridors should navigate around these airspaces whenever possible. Class B, Class C, and Class D airspaces are depitced on Section and Terminal aeronautical charts.*
	Corridor (where possible) makes use of existing navigational infrastructure.	*NextGen innovations may not necessitate the use of radio based navigation like VOR however many existing airways have already been evaluated for the effects of air traffic, potentially similifying the analysis of airspace impacts.*
Supporting the AAM Business Case	Corridor siting along intermediate cities supports increased accessibility for potential users of the system.	*In many cases a corridor may overpass population centers which will experience higher airspace congestion and externalities (such as sound) as a result. To encourage equity and provide value in having a corridor pass overhead, considerations should be made as to where CEPs can offer accessibility to use the corridor to commute between the two ends of the corridor.*
	Corridor is of a distance long enough to impact consumer decisionmaking via reduced travel times.	*If a corridor is relatively short in distance yet the cost per passenger per mile is higher than traditional ground base land transportation (personal vehicle, train, etc.) the decision of time savings versus cost may limit the adoption of the service.*
	Bypass corridors are analyzed to ensure traffic along consecutive CEPs does not cause unncessary travel time increases.	*Similar to the previous criteria discussing cost competitiveness, if the service is not time competitve due to congestion along the corridor service adoption may be limited.*

	Corridor siting entering a large city follows a somewhat centralized path to limit excessive travel to and from the corridor to an aircraft final destination.	*Collocation with highways as demonstrated in the case studies generally supports this behavior, but a study into the location of vertiports within the city specific to the corridor location in discussion will produce best results.*
Geographic and Environmental Considerations	Corridor does not encourage flight over areas where geographic features introduce hazards when flying at low-altitude.	*Examples may include:* *Mountains* *Built environment structures such as towers, wind turbines, etc.*
	Corridor does not encourage flight over areas that woud cause significant impact to wildlife or natural resource preservation.	*This criteria is aimed at identifying areas that would be at risk of necessitating a full environmental assessment.* *Areas to consider may include national parks, wildlife refuges, and wilderness areas which are often identified on sectional aeronautical charts. Protected environment inventories from state and federal sources should also be identified.*
Interagency and Community Engagement	Identify agencies and entities at all levels (city, regional, state, federal) which may be impacted by externalities associated with AAM operations.	*Examples may include:* *Transportation departments to address traffic created at local vertiports* *Local emergency services to develop response plans* *Economic development commissions which may benefit from access to intermediate cities.* *See Figure 2 from Mendonca et al., 2022 for additional regulatory considerations*
	Identify advocacy groups relevant to areas impacted or local issues presented in the planning process.	*Examples may include:* *Environmental protection and preservation groups* *Local pilot associations* *Many federal agencies and state-level depatments of transportation have published public involvement toolkits to assist in stakeholder and community engagement.*
	Identify relevant regulation that may impact corridor siting and development.	*Examples may include:* *Noise ordinances* *Zoning requirements to consider siting over compatible land uses* *Protected environment inventories*

APPENDIX C

IN-DEPTH INTERVIEW WITH JEFF BOROWIEC, PH.D.

The following dialogue is a transcript of highlights selected from an in-depth personal interview with Jeff Borowiec, Ph.D. of the Texas A&M Transportation Institute (TTI). At the time of this interview, Dr. Borowiec's time at TTI was coming to a close as he transitioned into a role in consulting for aviation planning particularly related to AAM. Only highlights of the transcript are recorded here as some of the discussion fell outside of the scope of the final representation of this study. Portions of the discussion upon review jump too far into specifics of State of Texas assessments of AAM and the stakeholders within committees addressing the topic, ultimately not information specifically relevant for the creation of a generalized framework for planners. For that reason, only questions and responses discussing AAM business models, concerns, traffic management, and regulatory climate as it might pertain to AAM corridors. The interview was conducted on the morning of Tuesday, March 20, 2023.

Q: "What kind of performance constraints might exist among the various aircraft associated with AAM outside of just speed and noise that will impact decision making for siting an AAM corridor within urban environments?"

A: "Manned versus unmanned aircraft capabilities come to mind as well as what equipment each would have onboard to interface with some form of traffic management. While UAM aircraft going through certification are going to have traditional ADS-B and radios, the smaller drones [you see commercially available today] could have relevance within the future scope of AAM yet are not equipped like modern small aircraft."

As a follow-up to the previous question, the researcher next prompted Dr. Borowiec with…

Q: "Is the difference between manned and unmanned aircraft an issue which necessitates segregating air traffic through a system such as UTM?"

A: "The difference brings up the problem of manned priority. Should aircraft with humans on board be given a right-of-way when in conflict with UAS carrying cargo? The same applies to the use case of transferring medical supplies and organs that many have been promoting in support of UAM, do drones doing that job receive priority? [You get into a] very difficult question when you begin to think about it in determining who or what matters [or does not]."

Considering the potential for conflict among AAM operations, the conversation next moved towards discussing conflicts between existing air operations and proposed AAM operations…

Q: "How might the interactions involved in transitioning from the vertiport environment and into the NAS look? Might an intermediate UTM need some level of coordination before aircraft climb into airspace controlled by ATC?"

A: "That is probably the most pressing issue of discussion is how UTM will interact [with the two critical aspects of ATS, ATC and TFM]. Again, when transitioning what has priority in sorting out those conflicts (as previously discussed) between aircraft or helicopters and a UAS or UAM aircraft climbing to a higher altitude." The interview moved to discuss who might have the responsibility to be equipped or yield to other aircraft as well as how data needed to coordinate conflict resolution is handled either by humans or by algorithm.

That discussion transferred from congested airspace to the same concept in less busy airspace…

Q: "Is there much of a need for AAM corridors outside of congested Class B airspaces, or does the existing NAS structure and developing UTM resources suffice?"

A: "Outside of congested airspace, you may see [only corridors as AAM-specific infrastructure] while the rest operate more similar to what you see in the NAS and drone regulations today, but there is still a question of how you resolve conflicts between traditional aircraft and UAS returns. The same question returns to how UTM applies not just to AAM aircraft outside of a controlled airspace."

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Q: "Does the momentum of UAM with AAM have enough momentum outside of technical aviation to have any sort of commercial viability that would necessitate creation of airspace and procedures specifically for AAM? What if small-scale commercial UAS operations continue to grow but widespread UAM adoption never really takes off outside of a few unique cases such as cities with extremely high population and employment density and have exceptional traffic struggles such as New York City?"

A: "It is possible that UAM does not take off to the level that manufacturers and trade organizations are theorizing at the moment and there is precedent for aerospace manufacturers overestimating the flying public's demand for certain services. The very light jet concept was originally seen as an innovative shift in the business jet space where everyone would have smaller personal jets to get around [take the Cirrus Vision Jet, Eclipse 500, or HondaJet for example]. People bought the aircraft, but it was not the total shift in consumer behavior that the industry believed it would be. There’s no doubt that UAM could be similar [however] UAM involved public belief in the technology rather than [private jet owners and operators] that the very light jet trend was targeting.”

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Q: “RAM might have relevance even in rural regions due to its ability to use existing airport infrastructure and connect rural areas to larger regional hubs. On the other side of AAM, outside of a few states that feature obvious candidates for UAM, is there significant regulatory interest in developing infrastructure or policy in this technology?”

A: “More than 20 [state or local regulatory agencies] have either published or are in the process of developing AAM/UAM reports, so regulators at all levels are showing some level of interest in the technology regardless of if it becomes widespread [in each agencies jurisdiction].”

— — —

Q: “As planners, you (Dr. Borowiec) and I (the researcher) have a bias towards establishing new systems, but is there anyone that is actively pushing back on the development of advanced traffic management systems”

A: “Businesses utilizing drones today are not overly receptive to a stricter enforcement of control or monitoring of UAS traffic, especially restricting movement to corridors. If [a present day UAS operator] benefits from little regulation today and the freedom to conduct operations as desired, [of course] there is some level of resistance that is voiced when regulators have sought user feedback [on AAM reports and studies].” Dr. Borowiec then proceeded to describe some of the legal arguments UAS operating companies presented in the development of a TxDOT UAM report. Although a conversation was had on regulatory literature at the state level and some aspects of juris precedent presented on specific scenarios. There was then direction to the case United States vs. Causby (1946) which nullified property claims to an infinite airspace above owned property, ruling in favor of navigable airspace above private property apart from certain low-level operations which may warrant compensation.