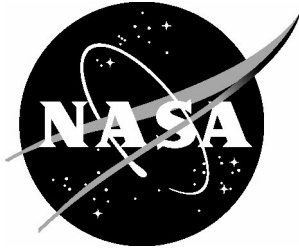


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Regional Air Mobility: Infrastructure Challenges, Passenger and Cargo Market Potential, and Sustainability Strategies for Underserved Airports

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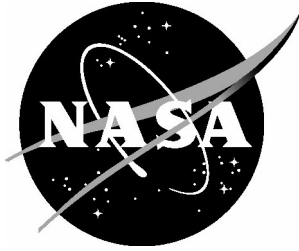
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ABSTRACT

This study explores the potential of Regional Air Mobility in transforming short-haul air transportation, with a focus on cargo operations and market sustainability for small, rural, and economically disadvantaged airports. The research examines the challenges and opportunities presented by the transition to electric aviation, particularly in terms of infrastructure development and investment requirements. Using data from the Bureau of Transportation Statistics, the study considers domestic air cargo markets and passenger routes under 500 statute miles for the state of Connecticut to identify potential Regional Air Mobility implementation opportunities. The paper discusses the NASA Airports as Energy Nodes activity at Tweed New Haven Airport as a case study for sustainable energy solutions in aviation. It also compares passenger and cargo market potentials, highlighting the need for a balanced approach in Regional Air Mobility development. For the state of Connecticut, belly and air freight represents approximately 1.6% of the national total combined freight with belly and air mail representing approximately 3.4% of the national combined total. Belly freight and belly mail account for approximately 0.2% and 0.3% respectively of the national total. Regional Air Mobility's estimated total addressable market is \$75 billion to \$115 billion by 2035 and it is further estimated to connect 300 to 700 million passengers annually utilizing existing airports. The study concludes by offering recommendations for infrastructure development, market entry strategies, and further research to support the successful implementation of Regional Air Mobility, emphasizing its role in enhancing regional connectivity and economic development.

I. INTRODUCTION

The dawn of electric aviation heralds a revolutionary shift in air travel, demanding a transformation of our airport infrastructure on an unprecedented scale. This electrification requires a network of strategically equipped airports capable of delivering large quantities of electricity to enable seamless, uninterrupted service. At the heart of this transformation lies a formidable challenge: the need for substantial investment in "refueling" – or more accurately, recharging – infrastructure. This financial hurdle looms particularly large for the diverse array of airports within the National Plan of Integrated Airports System (NPIAS), from which Regional Air Mobility (RAM) is set to operate. RAM's vision extends beyond major hubs to encompass small, remote, rural, and economically disadvantaged airports, promising to revitalize these often-overlooked facilities and their surrounding communities. However, the path to this electric future is fraught with complexities. While the transition will likely unfold gradually, allowing for phased upgrades and potential technological breakthroughs, the financial burden remains daunting, especially for smaller airports with limited resources.

The success of this electric aviation revolution hinges on a delicate balance of factors: government support, public-private partnerships, and tailored infrastructure solutions that can adapt to the evolving landscape of electric aircraft design. For the small, remote, rural, and economically disadvantaged airports at the focus of this study, the stakes are particularly high. Without access to the lifeblood of this new era – electricity – these facilities risk obsolescence, potentially triggering a cascade of economic decline in their communities. To secure their place in this electrified future, these airports must present compelling business cases that not only justify their continued relevance but also attract the investment necessary to keep pace with industry advancements. The challenge is clear: adapt and electrify, or risk being left behind in the contrails of progress.

Focusing on the cargo market as an entry point for RAM and predicated on the assumption that comparatively capable RAM aircraft will initially replace legacy aircraft on established routes, this research seeks to qualify market demand by identifying specific regional routes with sufficient cargo demand and show potential for creating new markets or expanding existing ones.

II. BACKGROUND

RAM stands poised to revolutionize short-haul air travel, offering a transformative solution for underserved communities, and revitalizing regional airports. While initial focus has been on Urban Air Mobility (UAM), industry leaders and researchers are increasingly recognizing RAM's superior market potential [1]. With an estimated total addressable market (TAM) of \$75 billion to \$115 billion by 2035, RAM promises to connect 300 to 700 million passengers annually, utilizing existing airports and overcoming regulatory hurdles more readily than its urban counterpart [2]. While this forecast focus is on passenger transportation, it suggests significant growth potential for the RAM market overall. It is reasonable to assume that some portion of this market could include cargo operations, especially given that cargo is often considered a potential early use case for new aviation technologies [3].

RAM's success hinges on leveraging advanced technologies, including electric and hybrid propulsion, to stimulate demand for point-to-point travel between underutilized airports [1]. This approach not only enhances regional connectivity but also addresses critical issues of equity, economics, and environmental sustainability [2]. As the industry evolves, RAM is expected to capitalize on existing networks while gradually expanding to new routes, potentially replacing legacy aircraft with more efficient, environmentally friendly alternatives [4]. However, the path to RAM's full potential is not without challenges. The industry must navigate energy infrastructure limitations, operational complexities, and the need for public acceptance [2][5]. Moreover, to truly fulfill its promise of equitable access and economic stimulation, RAM must extend beyond simply replacing existing routes to connect currently unserved communities [6]. This expansion will be crucial in maximizing RAM's impact and reach, ensuring it becomes a catalyst for regional development and not merely a technological upgrade of current systems. However, assuming that RAM will initially be introduced on pre-established passenger routes it is essential to qualify those routes for cargo as well such that RAMs potential can be realized.

A. NASA Airports as Energy Nodes Activity

NASA and the National Renewable Energy Laboratory (NREL) selected Winchester Regional Airport (OKV), a General Aviation airport, and Tweed New Haven Airport (HVN), an FAA Part 139 certified commercial airport, in the U.S. to participate in the "Airport as Energy Nodes ($\mathcal{A}ENodes$)" activity [7]. This initiative, part of NASA's Aeronautics Research Mission Directorate (ARMD) aims to research how airports can provide sustainable energy solutions for future aviation operations. The $\mathcal{A}ENodes$ activity will focus on:

- Developing energy solutions for zero-emission aviation, advanced/regional air mobility, and electrification of vehicles.
- Creating a virtual energy twin of OKV and HVN using NREL's Advanced Research on Integrated Energy Systems (ARIES) platform.
- Evaluating current and future operations and energy needs at OKV and HVN.
- Examining energy harvesting and fuel cycles for air and ground assets.
- Modeling shared airport-utility interaction for normal and emergency scenarios.

This research utilizes OKV and HVN case studies to analyze and project energy needs for present and future airport operations, establishing a roadmap for sustainable aviation infrastructure across the nation. The study emphasizes aircraft capabilities, payload capacity, and operational range requirements crucial for RAM. RAM aircraft are designed to transport up to nine passengers or equivalent cargo, with the versatility to operate from small community and public-use airports. The operational model envisions routes spanning at least 100 miles between origin and destination, leveraging the extensive network of 4,457 public-use airports throughout the contiguous United States [4]. This approach aims to revolutionize regional air travel by enhancing accessibility and efficiency while prioritizing sustainability.

B. Data Source

This study leverages the Bureau of Transportation Statistics (BTS) T-100 Domestic Market and Segment Data to analyze national, state, and local cargo and passenger markets, categorized by aircraft type (Table 1) [8]. This comprehensive analysis is crucial for identifying optimal routes for RAM implementation. The T-100 data provides valuable insights into air traffic patterns and capacity statistics and includes information on passengers, freight, and mail enplaned at origin airports and deplaned at destination airports. By analyzing this rich dataset, the research aims to identify trends, patterns, and opportunities in air travel that could inform the development and implementation of RAM services. This approach allows for a data-driven assessment of potential RAM routes, considering factors such as passenger demand, cargo needs, and existing air traffic patterns across different aircraft types and regional markets.

BTS T100 CODE	DESCRIPTION	AIRCRAFT TYPE EXAMPLES
0	Piston, 1-Engine/Combined Single Engine (Piston/Turbine)	Beechcraft 35/36, Cessna 150/152, 172, 180, 182, 195, 206, 207, 209, Pilatus PC6/350, Piper PA-32, 18, 14, 22, 24, 28
1	Piston/Turboprop, 2-engine	Tecman P2012, Aero Commander 500/6/680FL, Beech C-50, 18, King Air, Queen Air, Cessna T-50, C-421, C-310, C-340/335, C-402/402A, C-404
2	Piston/Turboprop, 2-, 4-engine	Boeing 377, Pilatus Britten-Norman BN2A, de Havilland DH-114, Douglas DC-4, DC-6, DC-7, Lockheed L-049, L-649, L-749, L-1049, L-1649
3	Turbine engine, helicopter, STOL	Bell B-47D/G/J, B-206A, Bell 212 Twin, Eurocopter AS350, Huges 300/500, Sikorsky S-51/55/58/61/62/76, DHC 6-400 Twin Otter
4	Turboprop, 2-engine	Beech 1300/18/99/C99/1900/200 King Air, Cessna C208/406/441, ATR-42/72, Dornier 228/328, SAAB-Fairchild 340, EMB 120 Brasilla, Mitsubishi MU-2z, Pilatus PC-12/PC6, de Haviland DHC 8/6, Shorts 330/360
5	Turboprop, 4-engine	Antonov 12/22, Canadair CL-44D, Ilyushin 18, Lockheed L-188/382/100, Shorts SH5, de Havilland Dash-7
6	Turbojet/Turbofan, 2-engine	Airbus A300, A310, A318, A319, A320, A321, A330, A350, Gulfstream G500, Bombardier Challenger 350, CRJ550, Learjet, Fokker F28-1000/4000/6000, Boeing 737, 757, 767, 777, Embraer-175. 135, 145, 140, 170, 190
7	Turbojet/Turbofan, 3-engine	Boeing 727, Douglas DC-10, MD-11, Lockheed L-1011, D, Tupolev 15, Dassult Falcon 50, 900, 7X
8	Turbojet/Turbofan, 4-engine	Boeing 707, 720, 747, Convair 880, Douglas DC-8, Airbus A340-200/300/500/600,

Source: Bureau of Transportation Statistics [8]

Table 1 T-100 Aircraft Type

C. Limitations of Prior RAM Market Studies

Georgia Institute of Technology researchers explored whether technological improvements and new operational concepts can revitalize the regional air mobility market segment, focusing on a model that exploits underutilized regional airports and state-of-the-art small aircraft [5] [9]. By applying a four-step demand model and a scheduling and fleet assignment optimization across the United States, the study quantifies demand for RAM services and identifies conditions for successful operations. The study addresses some aspects of market viability, including profitability and demand in underserved communities but does not consider market sustainability. RAM research tends to focus on aircraft systems, capabilities, and how it may perform in the passenger market segment [10] [11]. This suggests that there may be an imbalance in the focus of current research, with more emphasis placed on aircraft capabilities and performance in specific market segments, rather than on the market's ability to sustain these operations over time especially for small, rural, and economically disadvantaged airports.

The air cargo industry is experiencing significant growth and changes, with factors like e-commerce expansion and environmental sustainability practices driving new trends. However, the adaptation of this market to new aircraft types and routes in the context of RAM, particularly for cargo operations, has not been comprehensively studied or annualized in the same manner as the passenger market. This gap in research suggests an opportunity for further investigation into how RAM could potentially transform air

cargo operations, especially in underserved areas or for new types of cargo routes. For successful implementation of new aviation technologies or services like RAM, it is crucial to also assess market sustainability thoroughly.

D. Market Sustainability

In the case of commercial aviation, specifically air freight and mail, when a market cannot sustain operations due to economic forces, it is typically referred to as a "freight recession" or "cargo market downturn"[12] [13]. This situation is characterized by declining cargo volumes and revenues, reduced demand for air freight services, downward pressure on rates and yields, and overcapacity in the market. By way of example, the air cargo industry experienced a freight recession that began in early 2022, with the International Air Transport Association (IATA) estimating a 35% drop in airline cargo revenues in 2023 compared to the previous year [12]. During such periods, airlines and cargo operators may face challenges in maintaining profitability and may need to adjust their operations, capacity, and strategies to navigate the economic headwinds.

Commercial airlines employ several strategies to sustain cargo operations during both good and bad economic conditions. Airlines adjust their cargo capacity based on market demand. During economic downturns, they may reduce capacity to maintain higher freight rates and optimize profitability [14]. Carriers often balance their operations between passenger and cargo services. When passenger demand is low, they can focus more on cargo to offset losses [14][15]. Airlines invest in technologies and operational improvements to reduce costs and increase efficiency, which helps them remain competitive in challenging times [16][17]. Implementing environmental sustainability measures, such as the use of RAM, can lead to long-term cost savings and improved market positioning [16][18]. Airlines adjust their strategies based on market conditions, focusing on high-demand routes or sectors during economic downturns [14][19]. Extending airline networks further into small, underserved communities could enable more robust and economically sustainable networks. Carriers use economic slowdowns as opportunities to prepare for future upswings by investing in new technologies and improving their services [17][19]. RAM can be viewed as one such technology and its use may facilitate alliances or partnerships to share resources and reduce operational costs during challenging times [20].

Actual implementation of RAM may vary depending on specific market conditions, regulatory environments, and technological readiness. However, it is plausible to assume that adoption of RAM will align with general principles of technology adoption and market entry strategies in the aviation industry. Using pre-existing routes allows RAM operations to utilize existing airport infrastructure, which is more cost-effective than building new facilities. Replacing legacy aircraft on established routes provides a direct comparison of performance and efficiency, serving as a practical proof of concept (market validation). This approach allows for a phased introduction of new technologies, which is common in the aviation industry due to safety and regulatory considerations. Using established routes helps in managing operational risks while demonstrating the capabilities of new RAM aircraft. The RAM market is taking shape with investments in various technologies and infrastructure, which supports the idea of gradual adoption starting with existing routes [2].

E. Alternative Markets - FedEx

FedEx has long relied on Cessna Caravan turboprops for its regional cargo feeder network, with the aircraft becoming a cornerstone of its operations since the 1980s. The company played a pivotal role in shaping the Caravan's design, particularly its cargo pod, to meet its logistics needs [21]. In 2025, the Caravan still comprised nearly 80% of FedEx's feeder fleet, serving smaller markets with time-sensitive deliveries while maintaining low operating costs and reliability [21][22].

In 2017, FedEx became the launch customer for the Cessna 408 SkyCourier, a next-generation twin-engine turboprop designed in collaboration with Textron Aviation [22][23]. The SkyCourier addresses limitations of the Caravan with:

- Double the payload capacity: 6,000 lbs. vs. the Caravan's 3,070 lbs. [22][24].

- Large cargo door (87" x 69"): Enables handling of containerized (LD3) and palletized freight, streamlining operations for priority shipments [22][23].
- Modernized features: Twin-engine safety, digital cockpit, and flat cabin floor for efficiency [22][23].

FedEx plans to phase out its 238 Caravans, replacing them with 50 SkyCouriers (and options for 50 more) starting in 2020 [22][24]. By early 2023, partner carriers like Mountain Air Cargo began revenue flights with the new aircraft, initially deploying them on routes such as Tallahassee to Orlando [25][26]. The SkyCourier aligns with FedEx's broader fleet modernization strategy to:

1. Enhance efficiency: Lower operating costs and fuel consumption compared to older models [22][24].
2. Expand service capabilities: Access markets requiring larger cargo capacity and container compatibility [21][23].
3. Strengthen feeder networks: Complement reductions in widebody operations by optimizing regional airfreight agility [22][25].

F. Alternative Markets - UPS Flight Forward

UPS Flight Forward, the drone delivery subsidiary of UPS, has ordered 10 Beta Alia-250 electric Vertical Takeoff and Landing (eVTOL) aircraft with an option to purchase 140 additional units [27][28]. These aircraft are designed to transport time-sensitive cargo directly between UPS facilities, bypassing airports and traditional logistics bottlenecks. The partnership aims to create a "micro air feeder network" by leveraging on-site takeoff/landing capabilities at UPS hubs [27][29]. The Alia-250 eVTOL features:

- 1,400-pound payload capacity, accommodating urgent shipments like pharmaceuticals or critical documents [29][30].
- 250-mile range on a single charge, with a cruising speed of 150–170 mph [27][29].
- Zero operational emissions and reduced noise compared to conventional aircraft [27][31].
- Modular charging stations that recharge the aircraft in under an hour and support electric ground vehicles [28][29].

The strategic benefits for last-mile delivery include:

1. Operational Efficiency
 - Eliminates airport transfers, reducing ground handling and labor costs [27][28].
 - Enables direct "facility-to-facility" routes for time-critical deliveries, cutting transit times by up to 50% in small markets [27][29].
2. Environmental Sustainability
 - Aligns with UPS's goal to achieve carbon neutrality by 2050, replacing fossil fuel-dependent feeder aircraft [30][31].
 - Charging infrastructure repurposes used aircraft batteries, minimizing waste [28].
3. Scalability
 - Beta's aircraft are designed for eventual autonomous operation, pending FAA certification and regulatory advancements [27][32].
 - UPS plans to integrate the Alia with its existing drone network, which holds FAA Part 135 certification for payloads up to 7,500 lbs. [29][33].

In 2023, UPS tested the Alia in the UAE under a temporary license, exploring cargo missions in desert environments [34]. Beta's military collaboration includes \$43.6 million U.S. Air Force contracts for Alia testing that could fast-track certification and operational readiness [35][36]. Further, CAE (a global aviation training firm) is developing customized pilot and maintenance programs for UPS crews [37]. UPS aims to deploy the Alia alongside autonomous Cessna Caravans, creating a hybrid fleet for diverse cargo needs [32][38]. These partnerships position UPS at the forefront of electric air logistics, offering a blueprint for agile last-mile delivery in both urban and remote regions.

G. Alternative Markets - UAS

Unmanned Aerial System (UAS) cargo carriers like Elroy Air and others are revolutionizing logistics through innovative designs and autonomous technologies. Their approaches address critical challenges in efficiency, environmental sustainability, and accessibility for both military and commercial applications. By merging autonomy, cutting-edge aerodynamics, and sustainable propulsion, these UAS carriers are redefining cargo logistics for time-sensitive, remote, and high-volume deliveries. Listed below are some of the companies at the forefront of developing autonomous and efficient cargo delivery solutions using unmanned aerial systems [39], addressing various payload capacities and range requirements for different logistics applications:

1. Elroy Air is developing the Chaparral, an autonomous hybrid-electric vertical takeoff and landing (VTOL) cargo aircraft designed for middle-mile logistics.
2. Dronamics is developing the Black Swan, a long-range cargo drone with payload capacity and range designed to revolutionize same-day delivery.
3. Natilus is creating blended-wing-body freighters with larger cargo volume and reduced emissions compared to traditional aircraft.
4. Zipline specializes in autonomous delivery systems for instant logistics, particularly in healthcare.
5. Matternet has developed commercial drone delivery systems for urban and suburban environments.
6. Sabrewing Aircraft Company is developing heavy-lift cargo drones like the Rhagal, capable of carrying up to 2 metric tons vertically

III. AIR CARGO SERVICE AND RAM

A typical airport cargo market analysis combines quantitative data analysis with qualitative assessments to provide a comprehensive view of the airport's position and potential in the air cargo market. This informs strategic planning, infrastructure investments, and efforts to attract new cargo business. Table 2 lists the categories of a typical airport cargo market analysis and provides descriptions of each study segment. For airports without existing cargo volumes, the focus would be on identifying potential demand and necessary infrastructure investments and developing a long-term strategy to attract cargo operations. The study would emphasize the airport's unique value proposition and its potential role in regional economic development.

Every airport is unique, varying in size, location, capabilities, services, and operations. This study does not aim to deliver a generic "one size fits all" assessment of an airport's cargo potential amidst a rapidly evolving landscape. Instead, it seeks to empower small, rural, and economically disadvantaged airports—often unable to afford consultants—to effectively evaluate and enhance their cargo capabilities relative to RAM. By providing accessible guidance, this study aims to bridge the resource gap and help these airports capitalize on emergent cargo opportunities.

AIRPORT CARGO MARKET ANALYSIS (typical)	
SEGMENT	DESCRIPTION
Traffic Volumes	Analysing historical and current cargo tonnage handled by the airport, including breakdowns by domestic and international, import and export, etc.
Capacity	Assessing the airport's cargo handling capacity, including warehouse space, ramp areas, and specialized facilities like cold storage.
Airlines and Routes	Evaluating which cargo airlines and integrators serve the airport and on what routes. This includes both dedicated freighter and belly cargo capacity.
Commodities	Analyzing the types of goods being shipped through the airport and key industry sectors driving demand.
Infrastructure	Examining road and rail connections to assess the airport's connectivity to its catchment area.
Competitive Landscape	Comparing the airport's cargo performance and capabilities to other airports in the region.
Economic Factors	Considering regional economic indicators, trade patterns, and industry trends that impact air cargo demand.
Regulatory Environment	Assessing customs procedures, security requirements, and other regulations affecting cargo operations.
Technology	Evaluating the airports adoption of cargo handling technologies and digitalization efforts.
Growth Projections	Forecasting future cargo volumes based on market trends, planned infrastructure investments, and economic outlooks.
SWOT Analysis	Identifying the airport's strengths, weaknesses, opportunities, and threats in the cargo market.
Stakeholder Input	Gathering insights from airlines, freight forwarders, shippers, and other key stakeholders.
Benchmarking	Comparing key performance indicators to industry standards and best practices.

Source: [ACI Chapter 2 Developing an Air Cargo Market \[40\]](#)

Table 2 Typical Airport Cargo Market Analysis

A. Passenger-Freight Combination Service

Air freight service types include express air freight, consolidated air freight, and charter air freight (dedicated aircraft for specific cargo needs). Belly freight falls into the category of passenger-freight combination service. This type of air freight service utilizes the cargo hold space in passenger aircraft to transport goods alongside passengers and their baggage. Key characteristics of belly freight include:

- It is offered by commercial airlines primarily focused on passenger transportation.
- Cargo is carried in the lower deck or "belly" of passenger aircraft.
- It serves as a secondary source of revenue for passenger airlines.
- The cargo capacity is limited by the available space after accommodating passenger baggage.
- It is subject to the routes and schedules of passenger flights.

Belly freight is distinct from dedicated cargo services provided by all-cargo airlines or freighters, which use aircraft specifically designed for transporting freight [41]. Approximately half of global cargo volume, excluding shipments transported by integrated express carriers, is carried in the lower hold of passenger aircraft [12].

While RAM could potentially extend an airline's reach into currently non-serviced communities by way of belly freight, the focus of RAM is generally more aligned with passenger transport and short-haul connectivity rather than cargo transport specifically. The integration of RAM for belly freight would depend on several factors, including aircraft design, market demand, and operational feasibility,

B. RAM Cargo Market Demand Potential

RAM has the potential to significantly enhance air transport efficiency, expand service offerings, and meet the evolving demands of both passengers and cargo markets [42][43]. As has been illustrated, RAM's potential passenger market remains the focus of study for this burgeoning transport system. The air cargo market for RAM has not yet received the same level of scientific scrutiny as the passenger market. As airlines increasingly rely on passenger aircraft for cargo transport, RAM can optimize belly freight capacity by offering additional routes and services that complement existing passenger flights. This approach not only maximizes the use of available space in passenger aircraft but also helps to alleviate the strain on dedicated freighter capacity. Further, the growth of e-commerce has created a surge in demand for rapid delivery services, particularly for high-value and time-sensitive goods [44]. RAM can tap into this market by providing quick and efficient transportation options that utilize existing passenger networks, thereby facilitating faster delivery times and meeting consumer expectations. By employing innovative aircraft with electrified powertrains, RAM can offer a more sustainable alternative for

transporting both passengers and cargo. This not only reduces operational costs but also addresses environmental concerns associated with traditional aviation, making it an attractive option for both operators and consumers. Last, collaborating with freight forwarders and logistics providers will be crucial for RAM to effectively integrate belly freight into its operations. Establishing partnerships can help streamline logistics processes and enhance service offerings, ultimately driving demand for RAM services [45]. The importance of partnerships in air cargo operations and the need for comprehensive understanding of air freight movement at various levels are paramount to developing an airport business use case for RAM air freight.

IV. DOMESTIC AIR FREIGHT AND AIR MAIL

The Federal Aviation Administration (FAA) defines domestic operations for air cargo as those conducted between any points solely within the 48 contiguous states or the District of Columbia and entirely within any state, territory, or possession of the United States [46]. Air cargo is transported by way of air carrier aircraft carrying passengers or cargo for hire under 14 CFR Part 121 (scheduled air carriers, including major airlines and large cargo operators) and 14 CFR Part 135 (commuter and on-demand operations, typically with smaller aircraft). The FAA categorizes cargo based on its nature. General Cargo, which includes items that do not require special handling or precautions during air transport, and Special Cargo, which includes various subcategories such as dangerous goods, live animals, perishable cargo, and time and temperature sensitive products [47].

A. Air Mail

Air mail is considered separately from air freight, and while they share some regulatory similarities, there are distinct differences between the two. Air mail is managed by postal organizations, which handle the door-to-door chain for shipments, except for the airport-to-airport segment. In contrast, air freight is typically managed by freight forwarders or airlines throughout the entire shipping process [48]. Both air mail and air freight are subject to aviation security regulations and customs clearance procedures, but the specific requirements and processes may differ. Air freight often involves more complex customs clearance procedures, which may necessitate the assistance of freight forwarders or customs brokers [49]. Conversely, air mail may benefit from simplified customs processes, particularly for smaller items, although it remains subject to security screening and import/export regulations [50]. IATA has developed regulations for transporting different types of air cargo, including air mail. These regulations are designed to ensure the safe and efficient transport of goods and are regularly updated to reflect the latest industry standards [51].

B. Domestic Air Freight and Mail

Table 3 delineates quantities of domestic passengers, freight, and air mail (measured in pounds) broken out by BTS aircraft type. Cumulatively, table 3 represents all domestic carriage for calendar year 2023 with 828,977,901 passengers, 1,384,759,547 lbs. belly freight, 251,616,331 lbs. belly mail, 24,511,935,218 lbs. air freight, and 585,678,499 lbs. air mail.

NATIONAL	BTS AIRCRAFT							
	TYPE-1	TYPE-2	TYPE-3	TYPE-4	TYPE-5	TYPE-6	TYPE-7	TYPE-8
PAX	483,417	22,386	816,181	2,262,896	1,780,523	617,911,748	70,306,831	135,393,919
BELLY FREIGHT (lbs.)	1,485,485	128,391	23,766,373	19,196,700	-	869,875,329	25,111,821	445,195,448
BELLY MAIL (lbs.)	595,145	1,622,912	8,723,554	40,322,861	-	129,793,617	11,286,789	59,271,453
AIR FREIGHT (lbs.)	57,987,416	3,097,426	1,132,090	145,866,415	38,665,331	17,854,167,636	3,418,123,828	2,992,895,076
AIR MAIL (lbs.)	1,908,692	2,895,873	1,531,034	29,432,254	23,277,806	363,780,479	63,804,602	99,047,759

Source: Bureau of Transportation Statistics [8]

Table 3 2023 National Passengers, Freight, and Mail by BTS Aircraft Type

Belly freight represents approximately 5% of total freight carried (belly freight plus air freight) across all BTS aircraft types. Belly mail represents approximately 30% of total mail carried (belly mail plus air mail) across all BTS aircraft types.

C. Belly Freight and Belly Mail Focus

As previously stated, RAM aims to utilize existing airport infrastructure, particularly underutilized smaller airports. This aligns with the existing airline network structure and could facilitate the integration of RAM into current cargo and mail operations. The potential for RAM to reduce operating costs by 30-50% compared to traditional turboprop aircraft could make it economically viable to serve routes that were previously unprofitable, potentially including those carrying belly freight and mail [52]. As referenced in McKinsey & Company's *Short haul flying redefined: The promise of regional air mobility*, the decline in regional air travel over the past decades, particularly for aircraft with 6 to 50 seats, is a reasonable market entry point for RAM which could revitalize these routes, making them viable for both passenger and cargo operations. With 90% of the American population living within a 30-minute drive of a regional airport [4], existing airports could support the expansion of airline networks through RAM, including cargo and mail services. The potential for RAM to bring profitable air services to over 140 airports in the Northeast Corridor alone, compared to the current 80 airports with commercial services, could naturally include belly freight and mail capabilities [5]. It is important to note that while the initial focus of RAM may not be on serving major air freight airports, the potential for freight and mail transportation is not entirely excluded. As the RAM ecosystem develops, there may be opportunities to integrate with existing cargo operations or develop new cargo-specific services using RAM aircraft and infrastructure.

V. STATE OF CONNECTICUT AIR FREIGHT AND AIR MAIL

According to the 2022 Connecticut Statewide Freight Plan Update, Connecticut's freight assets include 21,557 miles of roadway, 1,406 miles on the State National Highway System, 628 miles of freight railroad right-of-way, three deep-water commercial ports, one major cargo airport, and 590 miles of gas transmission pipeline [53]. The plan serves as a long-range strategic guide for Connecticut's multimodal freight transportation system and was developed in accordance with the 2021 Bipartisan Infrastructure Law, receiving approval from the Federal Highway Administration (FHWA) in January 2023. The report indicates that in 2019, \$110.5 billion in direct outbound, inbound, and intraregional freight moved on Connecticut's freight network. This activity is associated with 451,100 direct regional jobs, which account for nearly 20% of the state's economy and generate \$36.5 billion in income. Freight distribution by mode shows that trucks carry the majority of freight, accounting for 91% by tonnage and 89% by value. Ports represent 5% of tonnage, while rail accounts for 4%. Future projections suggest that truck freight is expected to increase by 20%, translating to over 31 million tons, by 2040, with truck value projected to grow by \$91 billion—a 39% increase. Rail freight is also anticipated to rise by 30% by 2040. The plan outlines several goals aimed at enhancing the freight transportation system, including improving safety and security, ensuring economic competitiveness and efficiency, optimizing operations and performance, maintaining a state of good repair, and promoting equity, environmental protection, and livability.

The 2022 Connecticut Statewide Freight Plan Update and the 2021 Bipartisan Infrastructure Law do not consider RAM as a future cargo transportation system for Connecticut. The FHWA also does not appear to consider RAM for freight transportation in Connecticut or elsewhere in the nation, focusing instead on traditional surface transportation modes and infrastructure improvements [54]. The FHWA's National Highway Freight Program, established by the FAST Act, aims to improve the efficient movement of freight on the National Highway Freight Network (NHFN). However, it does not explicitly address RAM or its potential impact on air cargo networks and ground transportation [55]. Despite the potential benefits of RAM in reducing short-distance cargo transport and its environmental implications, there appears to be a lack of collaboration between the FHWA and the FAA on this matter. As both agencies are part of the Department of Transportation (DOT), increased cooperation could be beneficial

for integrating RAM into national freight transportation objectives. The Biden-Harris Administration's recent focus on zero-emission freight corridors and advanced transportation technology grants demonstrates a shift towards more environmentally sustainable and efficient freight transportation methods. However, these initiatives do not explicitly mention RAM as part of their strategies [56] [57].

A. State of Connecticut – Freight and Mail

An analysis of the BTS T-100 Domestic Segment operations for the 2023 calendar year for the state of Connecticut reveals that Bradley International Airport (BDL), ranked 34th in the country for busiest cargo airports is Connecticut's primary and largest airport handling air cargo, underscoring its critical role in the state’s air freight operations and positioning itself as a northeast regional cargo hub [58]. Table 4 delineates passenger, combined freight (belly and air freight), and combined mail (belly and air mail) carried by BTS aircraft type for 2023 calendar year. Combined freight represents approximately 1.6% of the national total combined freight as denoted in Table 3 with combined mail representing approximately 3.4% of the national combined total. Belly freight and belly mail account for approximately 0.2% and 0.3% respectively of the national total. Again, focus is given to belly freight and belly mail based on the previously stated assumption that airlines could, with minimal effort, extend cargo and mail networks to smaller and more remote airports by capitalizing on anticipated RAM passenger service.

STATE Connecticut	BTS AIRCRAFT							
	TYPE-1	TYPE-2	TYPE-3	TYPE-4	TYPE-5	TYPE-6	TYPE-7	TYPE-8
PAX	-	-	-	831	1,956	5,045,783	811,763	1,277,122
BELLY FREIGHT (lbs.)	-	-	-	-	-	2,185,930	41	883,106
BELLY MAIL (lbs.)	-	-	-	-	-	364,674	4,426	391,144
AIR FREIGHT (lbs.)	-	-	-	-	-	324,556,436	4,066,906	-
AIR MAIL (lbs.)	-	-	-	-	-	17,205,227	1,145,552	-

Source: Bureau of Transportation Statistics [8]

Table 4 2023 State of Connecticut Passengers, Freight, and Mail by BTS Aircraft Type

B. Regional Air Mobility: Transforming Short-Distance Aviation with Innovative Aircraft Solutions

It is reasonable to presume that BTS aircraft types 1 through 5 (piston and turboprop) indicated in Table 1 are likely targets for replacement with RAM aircraft for both passenger and cargo operations. RAM aircraft are designed to serve short to medium-range routes, typically between 50-500 miles, aligning with the operational range of many piston and turboprop aircraft. These new aircraft are envisioned to seat between 9 and 30 passengers, consistent with the capacity of many BTS types 1-5 category aircraft. RAM aims to utilize existing airport infrastructure, particularly smaller regional airports, which are often served by piston and turboprop aircraft. The development of electric and hybrid-electric propulsion systems for RAM aircraft is well-suited to replace older piston and turboprop engines, offering potential improvements in efficiency and environmental impact. This technological advancement, coupled with the ongoing decline in the production of small regional aircraft, may encourage operators to invest in new RAM technologies rather than extending the life of existing piston and turboprop fleets [2]. Furthermore, RAM aircraft are being designed to operate with reduced crew requirements and increased automation, potentially making them more cost-effective replacements for current BTS type 1-5 aircraft. These factors collectively suggest that RAM aircraft are well-positioned to replace or supplement existing piston and turboprop aircraft in regional transportation networks for both passenger and cargo operations.

RAM aims to revolutionize short-distance air travel. This innovative concept seeks to revitalize underutilized local airports while connecting regions, small towns, and rural areas, thereby offering a fresh alternative to existing regional transportation options. RAM's primary objective is to bridge the gap for underserved communities by providing efficient air transportation for shorter distances, addressing a niche currently neglected by traditional commercial aviation. According to a study conducted by the NASA-funded Georgia Tech Air Mobility Research Center, titled *The surprising market demand for*

regional air mobility, these underserved communities are loosely defined as those with limited or no scheduled commercial flights to major hubs or other destinations. Despite proximity to regional airports, many Americans find themselves compelled to undertake lengthy drives to larger airports for their travel needs. Factors such as discontinued services, reliance on Essential Air Service (EAS) subsidies, and a general lack of efficient transportation options further characterize these focus communities. While traditional commercial aviation has struggled to maintain profitability on these routes due to high operating costs and oversized aircraft, RAM presents a promising solution. By employing more efficient, appropriately sized aircraft and capitalizing on existing airports, RAM has the potential to transform the economics of regional air travel, breathing new life into previously economically unsustainable routes. Therefore, RAM will initially focus on pre-established routes within the 500-mile range, as this approach allows for the utilization of existing airports and addresses current market gaps in regional air travel. However, “market gaps”, as indicated by currently available research typically relate to the transport of passengers, not cargo.

1. State of Connecticut - Origination and Destination

A review of 2023 BTS T-100 Domestic markets with routes less than 500 statute miles served by the State of Connecticut airports, showcased in Table 5, delineates origination and destination city pairs that may inform RAM market points of entry.

STATE TOTALS - ORIGINATION	DEPARTURES SCHEDULED	DEPARTURES PERFORMED	TOTAL PAYLOAD CAPACITY	SEATS	PASSENGERS	FREIGHT	MAIL
All BTC ACFT TYPES 1-8	30,406	32,394	1,437,955,984	4,197,079	3,569,071	149,483,160	2,420,797
All BTC ACFT TYPES 1-8 < 500 sm	7,912	8,361	259,488,819	804,513	664,534	12,657,813	61,257
ALL BTC ACFT TYPES 1 - 5 < 500 sm (all Type 4)	19	137	444,010	1,112	373	-	-
% < 500 sm	26.02%	25.81%	18.05%	19.17%	18.62%	8.47%	2.53%
% that is Type 1 - 5 (all Type 4)	0.24%	1.64%	0.17%	0.14%	0.06%	0.00%	0.00%

STATE TOTALS - DESTINATION	DEPARTURES SCHEDULED	DEPARTURES PERFORMED	TOTAL PAYLOAD CAPACITY	SEATS	PASSENGERS	FREIGHT	MAIL
All BTC ACFT TYPES 1-8	30,417	32,464	1,443,871,458	4,198,068	3,568,384	195,347,615	3,551,905
All BTC ACFT TYPES 1-8 < 500 sm	7,831	8,218	247,562,063	794,832	652,694	11,951,374	117,865
ALL BTC ACFT TYPES 1 - 5 < 500 sm (all Type 4)	25	137	456,510	1,114	433	-	-
% < 500 sm	25.75%	25.31%	17.15%	18.93%	18.29%	6.12%	3.32%
% that is Type 1 - 5 (all Type 4)	0.32%	1.67%	0.18%	0.14%	0.07%	0.00%	0.00%

Source: Bureau of Transportation Statistics [8]

Table 5 2023 State of Connecticut Origination and Destination by BTS Aircraft Type

As indicated, origination and destination (O&D) airports served by BTS aircraft types 1 through 8, operating routes of less than 500 statute miles (sm) account for less than 20% for passengers, 10% for freight, 5% for mail. On routes that are less than 500 sm and flown by BTS aircraft types 1 through 5, passenger traffic accounts for less than 1% and no freight or mail flown. Passenger traffic on these routes account for 137 departures at approximately 1,100 seats with fewer than 500 passengers flown for both O&D traffic in calendar year 2023. This unused capacity is economically unsustainable for an airline. Passenger traffic on these routes, primarily served by BTS aircraft type 4, shows potential for RAM passenger service. These flights could theoretically accommodate freight and mail, extending airline reach into smaller communities. This finding suggests that aircraft currently focused on passenger transport could be utilized for additional freight and mail services, creating an integrated approach to carrying passengers, freight, and mail on these regional routes.

2. Tweed New Haven Airport - Origination and Destination

Table 6 provides O&D traffic for the state of Connecticut National Plan of Integrated Airports System (NPIAS) airports for routes less than 500 sm. Emphasis is given to the HVN with 21 origination and 19

destination departures, 165 origination seats and 162 destination seats, and 60 origination and 66 destination passengers. Flown by BTS aircraft type 4, this data seems to indicate an over capacity for these subject routes making them an ideal market entry point for RAM aircraft. Further analysis is required to assess the need for the transportation of freight and mail on these routes as well as induced traffic stemming from the offloading of ground vehicle-based cargo transport.

ORIGINATION AIRPORT	DEPARTURES SCHEDULED	DEPARTURES PERFORMED	TOTAL PAYLOAD CAPACITY	SEATS	PASSENGERS	FREIGHT	MAIL
Hartford (BDL)	-	11	37,950	88	28	-	-
Bridgeport (BDR)	18	32	92,700	275	96	-	-
Plainville (CT1)	-	8	27,600	64	16	-	-
Simsbury (CT2)	-	1	3,450	8	2	-	-
Danbury (DXR)	-	7	24,150	56	30	-	-
New London/Groton (GON)	1	13	44,250	105	44	-	-
Hartford (HFD)	-	6	19,500	47	13	-	-
New Haven (HVN)	-	21	64,450	165	60	-	-
Waterbury (OXC)	-	38	129,960	304	84	-	-

DESTINATION AIRPORT	DEPARTURES SCHEDULED	DEPARTURES PERFORMED	TOTAL PAYLOAD CAPACITY	SEATS	PASSENGERS	FREIGHT	MAIL
Hartford (BDL)	-	11	37,950	88	27	-	-
Bridgeport (BDR)	24	38	119,100	323	155	-	-
Plainville (CT1)	-	7	24,150	56	11	-	-
Simsbury (CT2)	-	-	-	-	-	-	-
Danbury (DXR)	-	8	27,600	64	31	-	-
New London/Groton (GON)	1	14	47,700	113	48	-	-
Hartford (HFD)	-	7	22,950	55	19	-	-
New Haven (HVN)	-	19	65,550	152	66	-	-
Waterbury (OXC)	-	33	111,510	263	76	-	-

Source: Bureau of Transportation Statistics [8]

Table 6 2023 Origination and Destination Routes Less Than 500 Statute Miles

VI. PASSENGER + CARGO APPROACH

This study seems to indicate that RAM strategies that consider both passenger and cargo operations will be more adaptable to the markets RAM seeks to open. To position RAM for communities with cargo potential and limited passenger opportunities or limited passenger and nascent cargo potential, a passenger plus cargo approach should be adopted. This strategy can leverage the unique advantages of RAM aircraft and airport infrastructure to serve these markets effectively. RAM operators should consider developing dedicated cargo services for routes with high freight demand but low passenger potential. This approach allows for the optimization of aircraft and operations specifically for cargo transport, potentially using converted passenger aircraft or purpose-built cargo variants of RAM aircraft. Operators could utilize RAM aircraft with modular designs that can be quickly reconfigured between passenger and cargo configurations. This flexibility allows operators to adapt to changing market demands and maximize aircraft utilization across different route types. Operators can position RAM as a critical link in the supply chain by integrating with last-mile delivery services. This could involve partnerships with e-commerce companies, local delivery services, or logistics providers to create a seamless cargo transport network from regional hubs to remote communities. Operators can further develop niche cargo services tailored to the specific needs of underserved communities. This might include medical supply transport, just-in-time delivery for manufacturing, fresh produce and perishables transport, and critical spare parts delivery for remote industries. Leveraging the ability of RAM aircraft to operate from smaller, underutilized airports can reduce infrastructure costs and provide more direct routing for cargo shipments, potentially improving delivery times and reducing overall logistics costs [4].

A. Economic Drivers for Passenger + Cargo Focused RAM

Economic drivers play a crucial role in shaping economic outcomes and performance, particularly in supply chain management where they quantify the financial impacts of decisions to optimize outcomes. In the context of RAM, these drivers are especially significant. RAM aircraft, particularly those utilizing electric or hybrid-electric propulsion, are anticipated to operate at lower costs compared to traditional passenger and cargo aircraft. This cost advantage has the potential to transform previously unprofitable routes into economically viable ones [59]. RAM's use of smaller, tailored aircraft for regional operations enables more frequent and efficient services to communities that lack sufficient passenger or cargo volume for larger aircraft. The environmentally friendly nature of RAM aircraft may also help overcome community resistance to increased flight frequencies at regional airports [60]. Furthermore, positioning RAM as a solution for enhancing connectivity and fostering economic development in underserved areas could attract government support or subsidies, akin to existing programs like the EAS [60]. This approach will be crucial to position the airport for Public-Private Partnerships (PPP) discussed in the following section. By adopting strategies that combine passenger and cargo services and capitalizing on the unique advantages of RAM aircraft and airport infrastructure, operators can effectively cater to communities with significant cargo potential but limited passenger demand or limited passenger demand and nascent cargo potential. This approach not only addresses the specific needs of these markets but also contributes to the overall economic viability and growth of the RAM sector, creating a more sustainable and inclusive air transportation ecosystem.

B. Public Private Partnership

PPPs are envisioned to play a crucial role in RAM strategies and will serve as a significant economic driver for its development. These partnerships are essential for addressing the unique challenges and opportunities presented by RAM, particularly in underserved communities with cargo potential but limited passenger demand or limited passenger demand and nascent cargo opportunity. PPPs will facilitate the integration of RAM into existing transportation networks and help overcome infrastructure and regulatory hurdles. The FAA's AAM Implementation Plan emphasizes leveraging PPP to identify key locations and use cases of interest to AAM industry stakeholders while promoting an all-hands approach to integration [61]. This collaborative approach allows for the coordination of various stakeholders, including vehicle manufacturers, operators, infrastructure developers, investors, and local governments.

In the context of cargo-focused RAM, PPPs can help fund and develop the necessary energy infrastructure for RAM operations, including charging stations. This is particularly important for cargo operations, which may require specialized facilities for loading and unloading freight [62]. Partnerships between government agencies and private companies can accelerate the development of technologies crucial for efficient cargo operations, such as autonomous flight systems and electric propulsion [2]. PPPs can facilitate the creation of appropriate regulatory frameworks that address the unique needs of cargo-focused RAM operations, ensuring safety and efficiency [61]. By sharing risks and resources, PPPs can make previously unprofitable routes economically viable for passenger and cargo operations. This is especially relevant for RAM, which aims to serve underutilized airports and connect regions that are currently underserved by traditional aviation [5]. PPPs can help ensure that RAM cargo operations are integrated into local communities in a way that maximizes economic benefits while minimizing negative impacts. This includes addressing concerns related to noise, emissions, and land use compatibility [62].

As an economic driver, PPPs in RAM can stimulate regional economic growth in several ways to include the creation of new market opportunities. By enabling efficient cargo transport to underserved areas, RAM can open up new markets and business opportunities [2]. Further, the development of RAM infrastructure and operations can create jobs in various sectors, from aviation to logistics and support services and attract additional private investment into RAM and related industries, further driving economic growth [63]. RAM is capable of improving supply chain efficiency by enhancing regional supply chains, potentially reducing transportation costs and improving delivery times for businesses [2]. The NEXA Capital Partners white paper emphasizes the importance of PPPs in developing UAM, which can be applied to RAM as well. It suggests that consortia formed on a city-by-city basis can create cost-

effective funding and infrastructure development models [64]. This approach could be particularly beneficial for cargo-focused RAM strategies, allowing for tailored solutions that address the specific needs and opportunities of each region.

VII. CONCLUSION AND RECOMMENDATIONS

RAM offers a promising solution for underserved communities, particularly small, rural, and economically disadvantaged airports. Cargo operations represent a potential early entry point for RAM technologies, though current research has predominantly focused on passenger markets. Expanding the body of research, allowing for a more rigorous assessment of cargo potential nationally for RAM, is essential for RAM to realize its potential. The successful implementation of RAM will require a holistic approach that balances technological innovation, infrastructure development, and market-driven strategies. Research indicates that the market entry strategy for RAM will initially focus RAM operations on pre-established routes under 500 statute miles, targeting less efficient and oversized legacy aircraft for replacement. Routes with existing passenger traffic that can accommodate potential cargo services should be prioritized over development of new routes, conducting a detailed market sustainability assessment for each potential RAM route. Investigation of operational models that integrate passenger and cargo services are indicated as cargo alone as a RAM market entry point seem economically unsustainable. Accomplishing this requires the development of flexible aircraft configurations to maximize route utilization. Further, the creation of tailored business use cases for small airports to attract investment are essential for airports to justify the capital investments required in support of RAM. Business use cases will require the exploration of diversification strategies that balance passenger and cargo operations on indicated routes. This strategy will inform long-term planning frameworks for both airports and airlines that account for technological advancements and market fluctuations.

A. Recommendations

1. Investigate how RAM could potentially transform air cargo operations in underserved areas or for new types of cargo routes with focus given to market sustainability.
2. NASA, through projects akin to Ænodes, should partner with the FAA, FHWA, and the Department of Commerce to collaboratively explore the integration of RAM into the National Highway Freight Program. Exploring RAM's potential impact on air cargo networks and ground transportation could be beneficial for integrating RAM into national freight transportation objectives.
3. Incorporate RAM as a strategy into zero-emission freight corridors and advanced transportation technology grants.
4. Recognize RAM market entry point for cargo is dependent upon existing passenger service. Partnering with stakeholders, create an integrated approach for RAM to carry passengers, freight, and mail on regional routes.

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