A42 – From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS

Final Report

November 10, 2023

v 1.1

NOTICE

LEGAL DISCLAIMER

The information provided herein may include content supplied by third parties. Although the data and information contained herein has been produced or processed from sources believed to be reliable, the Federal Aviation Administration makes no warranty, expressed or implied, regarding the accuracy, adequacy, completeness, legality, reliability or usefulness of any information, conclusions or recommendations provided herein. Distribution of the information contained herein does not constitute an endorsement or warranty of the data or information provided herein by the Federal Aviation Administration or the U.S. Department of Transportation. Neither the Federal Aviation Administration nor the U.S. Department of Transportation shall be held liable for any improper or incorrect use of the information contained herein and assumes no responsibility for anyone’s use of the information. The Federal Aviation Administration and U.S. Department of Transportation shall not be liable for any claim for any loss, harm, or other damages arising from access to or use of data or information, including without limitation any direct, indirect, incidental, exemplary, special or consequential damages, even if advised of the possibility of such damages. The Federal Aviation Administration shall not be liable to anyone for any decision made or action taken, or not taken, in reliance on the information contained herein.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
A11L.UAS.84_A42 Final Report		

4. Title and Subtitle	5. Report Date
A42 – From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS: Final Report	November 10, 2023
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Catherine F. Cahill, Ph.D. http://orcid.org/0000-000 Tim Bruner, https://orcid.org/0000-0002-7591-8823 Kurt Carraway, https://orcid.org/0000-0002-1362-8177 Tom Haritos, PhD., https://orcid.org/0000-0001-6546-383X Katie Silas, https://orcid.org/0000-0003-0647-4592 Rajagopal Sugumar, https://orcid.org/0000-0001-6262-1599 Catherine Cahill, PhD., https://orcid.org/000-0001-7575-6361 Mark Johnson, https://orcid.org/0000-0002-6524-1193 Robbie Lunnie, https://orcid.org/0000-0001-8850-8113 Evan Arnold, https://orcid.org/0000-0002-7725-9067 Steve Bert, https://orcid.org/0000-0002-4275-7082 Daniel Findley, https://orcid.org/0000-0003-4929-8613 Tracy Miller, https://orcid.org/0000-0003-4774-5598 Benjamin Noel, https://orcid.org/0000-0003-0177-2478 Jerry Hendrix Dustin Harrison Stephen Warr Nathan Webb, https//orcid.org/0000-0003-3900-1134	

9. Performing Organization Name and Address	10. Work Unit No.
University of Alaska Fairbanks, 2156 Koyukuk Dr., Fairbanks, AK 99775 Kansas State University North Carolina State University The Ohio State University University of Alabama Huntsville University of North Dakota	**11. Contract or Grant No.** A42 A11L.UAS.84

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Federal Aviation Administration FAA Sponsor: Sabrina Saunders-Hodge, AUS-300 UAS COE PM: Karen Davis, ANG-C2	Final Report (December 18, 2020 to December 22, 2023)
	14. Sponsoring Agency Code 5401

15. Supplementary Notes

16. Abstract

The use of large (> 55 lbs) Unmanned Aircraft Systems (UAS) to deliver cargo to communities across the country and around the world is one of the prime economic use cases for UAS. However there is a lack of information on how the safe integration of these larger aircraft into the National Airspace System. To obtain this information, the research team conducted a literature review of the current state of the field, performed interviews with current air carriers, conducted and observed large remotely-piloted or autonomous aircraft operations in Alaska, and performed an economic assessment of the costs and benefits of implementation of this technology. The economic assessment shows that the large Unmanned Aircraft Cargo (UAC) operations could be a major economic sector in the future and that upgrading existing airport infrastructure is the most likely way to economically implement the technology. The interviews show that air carriers are interested in implementing UAC if it is shown to be economically viable, but are waiting to see how the technology develops before investing in the technology. The flight tests show that; 1) converting traditional aircraft into remotely-piloted or autonomous aircraft and flying existing cargo routes and using existing infrastructure appears to be the fastest way to enter the UAC market in rural areas with minimal costs to the air carriers, 2) the pilots of the remotely-piloted aircraft believe the current set of rules and regulations is appropriate for the integration of the large, UAC aircraft into the NAS, and 3) weather will be one of the biggest challenges in implementing year-round cargo delivery. The results of this project show that the first potentially economically-viable implementation of large-scale UAC operations will be the integration of modified traditional aircraft into the existing airport infrastructure using current FAA rules and regulations. Further research on how to facilitate this implementation is required to ensure a safe integration of UAC operations in the NAS.

17. Key Words	**18. Distribution Statement**
Advanced Air Mobility, Unmanned Air Cargo, AAM, UAC, Unmanned Aircraft Systems, UAS, Air Cargo	No restrictions.

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	85	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF ACRONYMS

AAC	Advanced Air Cargo
AAM	Advanced Air Mobility
ACTK	Adjusted Cargo Tonne-Kilometers
ACUASI	Alaska Center for Unmanned Aircraft Systems Integration
APU	Auxiliary Power Unit
ATC	Air Traffic Control
ATM	Air Traffic Management
C2	Command and Control
CNSi	Communication, Navigation, Surveillance, Informational
CONOPs	Concept of Operations
CoA	Certificate of Authorization
DAA	Detect and Avoid
ENN	Nenana Municipal Airport
EVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FAI	Fairbanks International Airport
GCS	Ground Control Station
GSE	Ground Support Equipment
HLR	Heavy Long Range
HMR	Heavy Medium Range
NAS	National Airspace System
NCSU	North Carolina State University
NOTAM	Notice to Air Mission
PIC	Pilot in Command
ROC	Remote Operating Center
ROFA	Runway Object Free Area
STOL	Short Takeoff and Landing
sUAS	Small Unmanned Aircraft System
SMART	Simple Multi-Attribute Rating Technique
SVO	Simplified Vehicle Operations
UAC	Unmanned Aircraft Cargo
UAF	University of Alaska Fairbanks
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aircraft Vehicle
ULD	Unit Load Devices
UTM	Unmanned Aircraft System Traffic Management
VTOL	Vertical Takeoff and Landing

EXECUTIVE SUMMARY

The use of large (> 55 lbs) Unmanned Aircraft Systems (UAS) to deliver cargo to communities across the country and around the world is one of the prime economic use cases for UAS. However there is a lack of information on how the safe integration of these larger aircraft into the National Airspace System (NAS) and infrastructure will occur due to no aircraft being certified to conduct these operations and there being limited projections of the economic cost/benefit of implementing the technology. To obtain some of this information, the research team conducted a literature review of the current state of the field, performed interviews with current air carriers, conducted and observed large remotely-piloted or autonomous aircraft operations in Alaska, and performed an economic assessment of the costs and benefits of implementation of this technology.

The overarching conclusion from the interviews with the air carrier representatives is that they want to implement Unmanned Aircraft Cargo (UAC) operations if they are economically feasible and do not require a lot of new infrastructure, but are adopting a “wait and see” approach before implementing it to ensure that they are not wasting their time and money. Specifically, the companies think that if UAC is financially viable, they can expand services and make more frequent deliveries that will decrease constraints on crewed aircraft and mean less spoilage or thaw. However, they currently feel that the expected costs of implementing UAC are not economically feasible. They highlighted security and safety as glaring gaps in UAC operations.

Some of the key takeaways from the flight testing include: 1) converting traditional aircraft into remotely-piloted or autonomous aircraft and flying existing cargo routes and using existing infrastructure appears to be the fastest way to enter the UAC market in rural areas with minimal costs to the air carriers, 2) the pilots of the remotely-piloted aircraft believe the current set of rules and regulations is appropriate for the integration of the large, UAC aircraft into the NAS, and 3) weather will be one of the biggest challenges in implementing year-round cargo delivery.

The economic assessment's key findings show that from 2023 to 2045, an estimated 2,838 aircraft within the domestic air cargo fleet are projected to have Advanced Air Mobility (AAM) air cargo capabilities. Estimates indicate that these aircraft will facilitate approximately $2.6 billion in AAM cargo revenue in 2045 and $20.7 billion in cumulative revenue across the forecast period. New investments in AAM aircraft and ongoing expenditures to support their operations and maintenance will generate approximately $86.5 billion in direct output for the US economy from the present through 2045 (approximately $65.7 billion in capital expenditures and $20.8 billion in operations and maintenance expenditures). Over the same period, enabling infrastructure investments will generate approximately $14.5 billion in direct output for the US economy ($2.5 billion in capital expenditures and $12.0 billion in operations and maintenance expenditures).

It is difficult to pinpoint the precise locations where ground infrastructure investments will occur, but the findings suggest AAM air cargo regional and light use cases will likely rely on airport infrastructure upgrades including three-phase power and electric charging capabilities for traditional and vertical takeoff and landing aircraft.

The results of this project show that the first potentially economically-viable implementation of large-scale UAC operations will be the integration of modified traditional aircraft into the existing airport infrastructure using current FAA rules and regulations. Further research on how to facilitate this implementation is required to ensure a safe integration of UAC operations in the NAS.

1 INTRODUCTION & BACKGROUND

The Federal Aviation Administration's (FAA) 'Strategic Outlook for Cross-Cutting Research in Emerging Operations: UAS and AAM', presented in Figure 1 (FAA, 2023), shows the FAA's research plan to get to safe, routine, large (>55 lbs) Unmanned Aircraft System (UAS) Cargo (UAC) and Urban Air Mobility (UAM) operations, together known as Advanced Air Mobility (AAM). The figure highlights gaps in the FAA's understanding of how these operations will occur and what research needs to be done to fill the gaps. The near and mid-term research areas identified include what infrastructure is needed to support the integration of the large AAM aircraft, how quickly are large UAS projected to enter the air cargo and passenger transport markets, what are the potential impacts of large-scale AAM operations, how will the AAM aircraft interact with Air Traffic Control and other users of the National Airspace System (NAS), and a host of other questions.

Figure 1. FAA strategic outlook for cross-cutting research in emerging operations: UAS and AAM (FAA, 2023).

The FAA requires data on potential AAM operations and economic projections to be able to answer these questions. Currently, there is a dearth of data available on AAM aircraft operations in the NAS due to a lack of routine operations. This project focuses on obtaining some of the required data needed to assess what is needed to implement UAC through asking current UAS users and air carrier operators their expectations of what is needed to integrate UAC into current air cargo operations, conducting large drone operations in a real-world environment to observe what factors (e.g., infrastructure at the airports, aircraft characteristics, command and control links, etc.) need to be addressed before safe, routine UAC operations can occur, and conducting an economic assessment of the impact of increasing UAC operations on air carrier operations.

Specifically, the research team focused on collecting data to address the gaps in the FAA's understanding of what new and/or additional procedures, airspace rules, and equipment standards will need to be developed and/or modified to accommodate safe integration of UAC operations in the NAS that the program sponsor highlighted in the request for proposals. The identified areas of need were to:

- Understand trends in large UAS, particularly with a focus to understand its role in cargo delivery, both scheduled and unscheduled routine operations;
- Establish likely relationships between manned cargo transitioning into unmanned large UAS;
- Establish any significant change following the onset of COVID-19 and likely adoption of larger UAS in cargo carrying capabilities;
- Forecast large UAS, both civil and commercial, and transitioning small Unmanned Aircraft Systems (sUAS) requiring analysis of market including competition, technology, and the anticipated trajectories into nonsegregated airspaces together with anticipated timelines;
- Understand performance characteristics, reliability, and standards of large UAS and those sUAS anticipated to transition within the Air Traffic Control (ATC)-serviced airspaces (G, D, E, A, B, and C in probable order of importance) over the next few years;
- Understand performance requirements of ATC to allow large UAS to be flying in the airspaces (e.g., under what circumstances, can these large UAS fly within the Mode-C veils?);
- Understand separation requirements and/or rules for integration (i.e., Communication, Navigation, Surveillance, Informational [CNSi]) rules, in particular) into these airspaces;
- Understand requirements for type design, airworthiness, and production approvals (e.g., type certificates, airworthiness certificates, and production certificates); understand also how changes in these may facilitate regulatory initiatives such as MOSAIC;
- Understand safety risk management requirements for these integrations;
- Provide projection of workforce associated with these anticipated changes and implications on airspace requirements including procedures and regulations; and
- Provide an understanding of physical infrastructure required to facilitate large UAS delivering cargo incrementally in the NAS (e.g., redesigning of airport including ramps, delivery points, etc.).

Obtaining an enhanced understanding of these topics is necessary to understand and prioritize NAS resources and ensure aviation safety as these newer aircraft evolve in serving greater civilian and commercial needs such as air transportation of cargo.

2 APPROACH

The research team approached the challenge of identifying the current state of large UAC operations, the opportunities and barriers to the acceptance of the technology, and prediction of the growth of the UAC market through the following Tasks:

2.1 Task 1: Literature and Market Analysis

The research team conducted a literature review and market analysis aimed at addressing the research questions relating to the implementation of large UAS cargo carrying operations posed above. The literature review focused on the technical requirements for conducting cargo carrying operations in the NAS using large UAS, including the technology transition needed to allow autonomous operations, and the potential infrastructure requirements needed to facilitate deliveries. The market analysis identified market trends, potential for industry growth, cost comparisons with ground-based and current aircraft-based cargo deliveries, and the ramifications of establishing or adapting current cargo infrastructure in rural and moderately populated areas.

The literature review was finalized on October 12, 2021 (ASSURE A41/42 – Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations/From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS: Literature Review). The key findings for UAC from the literature review were:

1) UAC faces unique barriers to integration in contrast to UAM vehicles. Much of the information that exists for the integration and logistical implementation of cargo-capable aircraft operating at an airport is, in large part, conceptual because there are no large UAS conducting air cargo carrier missions in the NAS. Therefore, the literature is focused on the theoretical "how" to get cargo delivered. This means that there is no real-world information available to adequately determine best practices for integration and logistics of large cargo UAS at airports. Current manned air cargo operations will need to provide the basis for assessing what could be needed to implement UAC. Alaska, with its diverse air carrier fleet of aircraft, can serve as a surrogate for how different types and sizes of UAC aircraft can be integrated into traditional air cargo routes and operations.
2) Variables that influence UAC demand will include domestic and international economic variables including trends in the air cargo industry, trade flows, economic output, supply chain efficiencies, and projected growth. Other variables that influence UAC demand include the need to refill product inventories quickly, the desire to avoid delays due to other transport modes, such as ocean transport, and the regulatory barriers to implementing UAC.
3) COVID-19 increased the demand for air cargo services. The delays and shutdowns due to ocean transport and international supply chain failures and the desire for customers to quickly receive goods at home, caused transport companies to turn to air cargo in greater numbers.
4) Future growth trends need to be developed that incorporate domestic and international economic variables, including trends in the air cargo industry, trade flows, domestic and international economic output, supply chain efficiencies, and projected growth.

2.2 Task 2: Use Case Development

Using outputs from the literature review and market analysis, the research team determined the scope of use cases such that they (1) are representative of applicable market and technical trends for cargo delivery by large UAS, and (2) allow for research tasks to be completed within the allotted period of performance and budgetary constraints.

The North Carolina State University (NCSU) air cargo market analysis split the air cargo market into four sections that sum to provide the AAM Air Cargo number bold in Table 1to capture the common types of air cargo operations:

1. HLT - Heavy, long-range (>3000 nm) aircraft with payload capacities of greater than 40 T;
2. HMR - Heavy, medium-range (500-3,000 nm) aircraft with payload capacities greater than 10 T;

3. Regional - Regional-range (75-1,000 nm) aircraft with payload capacities from 1-10 T; and
4. Light – Short-range (<250 nm) aircraft with payload capacities from 50-1,000 lbs.

Table 1. Air Cargo Market Summary (Annual Revenue in Years 2035 and 2045 – In Billions of USD).

Market Segments	Air Cargo Revenue (2035)	Air Cargo Revenue (2045)
Traditional Aviation Air Cargo	**$29.49**	**$34.45**
AAM Air Cargo	**$0.84**	**$2.63**
HLR	*$0.77*	*$2.31*
HMR	*$0.05*	*$0.21*
Regional (feeder)	*$0.02*	*$0.11*
Light (EVTOL)	**$30.33**	**$37.08**
Total	**$29.49**	**$34.45**

The NCSU team examined the four sections and determined that the Regional market segment is a substitute for the current regional freight market and the Light market segment is a substitute for the current local freight market. They also determined that the infrastructure and types of operations needed to support Heavy Long Range (HLR) and Heavy Medium Range (HMR) air cargo are very similar, but are somewhat dissimilar from the other air cargo types. As a result, the research team decided to combine the HLR and HMR sections into one market segment (HLR+HMR) that focuses on heavy, longer-range aircraft. Therefore, the research team recommended that the use cases for this project be focused on the three groups of: HLR+HMR, Regional, and Light UAC.

2.3 Task 3: Experiment Plan

The research team developed a plan of attack for conducting the experiments they would carry out in Task 4. The experimental plan identified the key issues that needed to be addressed in each use case identified in Task 2 and outlined the experiments that they tailored to quantify the effects of those factors on the specific use cases. The research team contemplated several potential types of experiments: surveys of current activities and perceptions, simulations of aircraft operations or technologies, safety case development and Certificate of Authorization submission, lab or flight tests of specified technologies, mining of data from current manned operations, economic modeling, and projections of supporting technology growth, such as increased cellular and satellite coverage. After looking at the literature review and market analysis, the research team coordinated with the sponsor and selected subject matter experts to ensure that the experiments addressed the research questions identified for each use case and had an appropriate scope.

The A42 literature review and market analysis showed that experiments that quantified, through questioning current air cargo and drone operators and observing air cargo operations, information about the real-world integration and logistical implementation of cargo-capable UAS operating at an airport provided the best opportunities for valuable research. Therefore the team designed a survey, interview questions, and ground and flight operations that they would conduct as a part of Task 4 and would supplement the economic assessment and methodology effort in Task 5. The team designed the experiments, economic assessment, and methodology efforts to address research questions crossing the spectrum from economic demand, to ability to integrate UAC operations into the current air cargo environment, to potential new infrastructure and workforce needs.

2.4 Task 4: Conduct Designed Experiments

In Task 4, the research team conducted the experiments outlined in the Experimental Plan. The details and results of these experiments are included in Sections 4 and 5 of this report.

2.5 Task 5: Economic Assessment and Methodology

The research team devised a methodology for assessing the economic impact of implementing air cargo transport by large UAS. The key output of this task is a methodology and supporting data considering direct, indirect, and induced benefits of large UAS air cargo. The results of this effort are included in Section 6 of this report.

3 RESEARCH QUESTIONS

The research team used the market analysis and literature review to identify the types and varieties of information needed to answer the range of questions proposed in the request for proposal for the three use cases (HLR+HMR, Regional, and Light UAC operations). The questions include:

- What is the potential for large UAS in carrying air cargo in the US? Starting from road transportation and existing air cargo, it is expected that a potential market scope will be laid out.
- What are the likely effects of pandemics such as COVID-19 on adoption of larger UAS in cargo carrying?
- What is the likely location and distribution of large UAS to meet demand and growth of air cargo over a period of 10 years?
- What interface characteristics are necessary for the UAS pilot, existing and emerging businesses (e.g., package delivery under 14 Code of Federal Regulations Title 14 Part 135 and/or waiver trends) to maintain awareness of aircraft system state with automated aircraft system and subsystem control?
- What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?
- How can the autonomous systems be evaluated or certified such that safe integration of UAS in the existing Air Traffic Management (ATM) environment or emerging UAS Traffic Management (UTM) is enabled?
- How will the UTM paradigm integrate into the large UAS environment? Or will a separate paradigm be required? How will these traffic management paradigms be integrated with the NAS ATM that is already operational?
- How will strategic scheduling of large UAS occur?
- How will the non-scheduled large UAS be handled?
- What other resources and NAS investment may be necessary to facilitate growth of UAS in air cargo?
- What will be the aggregated economic benefits, i.e., direct, indirect and induced, of integrating large UAS in transporting air cargo on the overall economy?

The surveys, interviews, and economic assessment will explore the differences between these three use cases, while the flight testing will be confined to the Light and Regional cases due to the lack of HLR and HMR cargo drones available for testing.

4 SURVEY AND INTERVIEWS

4.1 The Survey

The research team developed a survey (see Appendix A for the survey and survey consent form) for distribution to a wide variety of Advanced Air Cargo (AAC) stakeholders including airport operators, Original Equipment Manufacturers, air carriers, end users, etc. The research team originally designed the survey to be broken into smaller, targeted surveys, each one of which would have gone to a different sent of key stakeholder organizations in one of the categories above. However, the challenge of separating all of the potential respondents into those categories due to teams having expertise across multiple areas was daunting and the time to get the survey done was limited, so the team ended up rolling all the questions into one survey. This was, in hindsight, an error. The resulting survey contained multiple sections designed to allow the survey respondent to select the questions on the topics they felt most competent to answer and separating the questions of most interest to the survey team from other helpful, but not critical questions, but the survey ended up being too long and complex according to feedback from UAF partners.

After the survey was approved through the research universities' Institutional Review Boards, it was sent to over 1700 valid email addresses gleaned from a University of Alaska Fairbanks (UAF) mailing list for the Global Autonomous Systems Conference. The survey was long and the team thinks that resulted in a response rate that was too low in each area of expertise to provide statistically significant information. The end of the project was approaching too quickly to allow for a complete revamp of the survey approach, resubmission through the Institutional Review Boards, and dissemination. The key lessons learned from the survey experience are: 1) do not let the pursuit of the most information keep prevent the collection of the minimum information needed, 2) targeting multiple stakeholders for specific questions during a survey is a challenge and it may be better to stick to more general information, 3) university Institutional Review Boards always take longer than expected to process the packages, and 4) purchasing help distributing a survey can be cost-effective.

4.2 The Interviews

Unlike with the survey, the research team had complete success, defined as every organization asked to participate in an interview agreed to participate, with the interview portion of experimental design. The interviews contained the top 12 questions from the survey the research team decided were the most critical information for answering the project's research questions (listed in Section 2). The questions predominantly focus on the issues directly related to current air carrier operations and the potential infrastructure investments and operational changes needed to implement UAC. Therefore the team proposed meeting with four current cargo air carriers of different sizes from small Alaskan regional cargo air carriers to large international cargo air carriers. The air carriers approached to participate in the survey were either participants in the FAA's BEYOND program, worked with one of the universities conducting this research, or participated in the strategic planning charrettes designed to bring representatives from all key stakeholders in Alaska to determine what is needed to safely integrate drones into the NAS. These air carriers are all working with Original Equipment Manufacturers to develop the UAS technologies needed to fly large drones for cargo operations across the U.S., create the concepts of operations for the safe usage of these drones, and identify the infrastructure needs at airports and in the NAS to support this technology, so they are uniquely qualified to opine on the survey's topics.

The questions, anonymized answers from the interviewees, and some key findings for each question are as follows:

What major Ground Support Equipment (GSE) is located at your largest operational locations (eg, hubs)?

1. De-ice trucks, hydraulic handling eq, fork lifts, belt loaders, fuel trucks. Auxiliary Power Units (APUs) start carts (air start units). Some unique eq[uipment] for the older stuff. These are places with roads. The sub/remote hubs have forklift, de-ice, trucks, and APUs also.
2. K-loaders, belt loaders, tugs, traditional large dollies, Unit Load Devices (ULD) and ULD staging racks, scales for weight, tow-bars, tugs, forklifts (for inside building operations only). Fuel and de-ice equipment are dependent on the location and activity level. Maintenance is provided for their fleet unless they are outside of one of their networks. No maintenance is provided on feeder aircraft on network between inside support. Maintenance is provided by outside contractors for certain contracts.
3. Forklifts, slave-pallets (platform with rollers), material handling for ULDs helps unload aircraft, other ground support equipment.
4. Belt loaders, dollies, ground power unit, K-loaders, APUs, forklifts, tugs, heaters, ground power units, ground cooling units, 185 aircraft gates, support airplanes, maintenance trucks, fueling vehicles, tow bar, and more.

Key Findings:

- The GSE located in hubs is pretty standard and includes k-loaders, forklifts, slave pallets, belt loaders, tugs, heaters, de-ice trucks, hydraulic lifts, fuel trucks, etc.
- The amount of GSE needed increases as a function of the size of the operation.

What major GSE is located at your smallest operational location (eg, equivalent of a "spoke" airport).

1. At one airport they don't really have anything. They are using the pickup truck that meets the airplane. The village leaders will help with larger cargo as needed. It is all basically the same as it has been in the spoke location with just newer trucks.
2. Certain cargo providers do not have gravel capacities and only go to relatively large airports in Alaska using only 737-200s. In more rural communities, minimal equipment is on hand. Operations in smaller airports (5,000 ft. paved with fire operations etc.) often include land, unload cargo, and return to a larger hub within an hour.
3. Most locations will include everything mentioned in the previous question. During peak season, operations may shuffle equipment around to accommodate the increased flow from the 139 airports for 121 operations. Most common piece of GSE would be a belt loader. Feeder contract takes care of basic minimum.

4. Smaller locations have a towbar that can attach to a tug. Smaller sort facilities have smaller belts with smaller footprint of the belts and loading trucks.

Key Findings:

- The needed GSE at the smallest operational locations also depends on the size of operation.
- More rural locations have fewer specialized GSEs and sometimes rely on community members to help with the operations.
- Some cargo providers do not have gravel capabilities and can only operate in the larger hubs.
- During peak season larger operations shuffle GSE at a location.

How has the pandemic affected air cargo operations (ground/flight crew number/density restrictions? Additional sanitation requirements? Increased/decreased demand? Other?)

1. Yesterday they basically decided it is back to normal. The workforce's willingness to accomplish the work has diminished. The cargo is still going well for them, but not as much as it was during the panic. Interviewees think it is labor that is the biggest noticeable change.
2. No lasting changes and currently over the effects of the pandemic as it wanes. The trend in Alaska is returning to normal. Currently there is less volume of cargo than before. During the height of the pandemic was the opposite, moving greater volume. Interviewee operated throughout the pandemic even through smaller locations within rural communities. People on the ground helped unload airplane with masks. No extra sanitation standards were observed other than mask-wearing.
3. A little late on this question. The pandemic dramatically impacted operations and companies scaled up with greater volume during the pandemic. There were extra precautions in place for safety and compliance with personal protective equipment but now everything is more relaxed. Post pandemic, the volume has dropped significantly due to various reasons including less reliance on time dependency, economy related issues, inflation, general economic state, and customers shifting demand to less time critical options of cargo (i.e. customers taking next day delivery vs same day delivery).
4. Interviewee states that they have returned to 2019 pre-pandemic levels in terms of volume. Passenger airlines carry large amounts of cargo that had to be carried by only cargo aircraft during the pandemic. During the pandemic the company adhered to sanitation procedures and even developed new methods of sanitizing the aircraft. Operations ramped up in 2021 and 2022, but currently coming back down to normal.

Key Findings:

- The pandemic dramatically impacted cargo operations. Companies scaled up due to the increased demand and moved greater volumes of freight at the height of the pandemic in 2021 and 2022.
- Companies adhered to regulations and sanitation requirements were met, but the processes were not an obstacle or a hindrance on operations.

    - The regulations and requirement would not have had a great impact on drone operations, but drone operations would have limited contact/exposure between people.
    - As automation increases, person to person contact would decrease.
- Post pandemic, companies are experiencing pre-pandemic freight delivery levels due to time reliance on dependency, economic factors, and customers shifting demand to less critical delivery (next day delivery vs same day delivery).

What are the primary changes you anticipate occurring to standard business practices due to the transition from traditional to AAC?

1. The interviewee thinks it will be very important to see what the infrastructure and training needs for the drones to be able to deliver. They currently have a pilot that takes care of the security and safety of the drone. They question who will properly monitor the loading and safety of the general operation.
2. There is general interest and attention to many of the AAC/AAM fronts for a positive impact on the industry. A goal is to create more flexible and lower operations costs and maintain a sustainability impact. The pilot shortage is outpacing demand for provided services causing them not to be able to maintain services to some areas due to cost. They hope they can expand their services with more AAC. Dollars and cents matter; it must be economically viable. Due Sustainable Aviation Fuel increases cost for them. In general, the AAC needs to be financially viable.
3. An interviewee expects to see more flight Foreign Object Damage. The addition of more UAS in the airspace may cause more potential damage. Currently there is no formalized adoption plans because the technology may be "too far away" and the challenges of smaller payloads lead to more frequent flights. Currently more companies are efficient with larger aircraft. However, there is general interest in the potential once the technology is at the marketable level: more frequent deliveries around the clock and with the less constraints on crewed aircraft. This greatly impacts rural communities because of more frequent cargo deliveries such as bypass mail. More flights leads to more deliveries and less cargo spoilage (i.e. melted ice cream). Tracking could be an issue and an increase of labor handling is expected.
4. The ability to have more time. Currently, time is dependent and tied to sorting facilities. Interviewee disclosed that they are transitioning to a more regional sorting facility approach than the current hub model.

Key Findings:

- The pilot shortage is outpacing demand for provided services causing the air carriers to not be able to maintain services to certain areas due to cost.
- The companies see infrastructure and training changing to support the transition from manned aircraft to unmanned aircraft.
- The interviewees highlighted security and safety as glaring gaps in the implementation of UAC.
- The companies have interest in the transition due to the potential economic benefits.
    - If UAC is financially viable, they hope they can expand services.

    - More frequent deliveries lead to less constraints on crewed aircraft (labor).
    - The companies hope they can expand their services through UAC.
        - This would greatly impact rural communities.
        - More frequent deliveries would mean less spoilage or thaw (e.g., melted ice cream)

What types of new <u>aircraft</u> equipment purchases / investments are you anticipating will be made due to the transition from traditional to AAC (if any)? Do you have an estimate of the upfront (capital) and ongoing (operations and maintenance) costs associated with these purchases?

1. This is still varying wildly. They have been approached by two drone companies. In 2017, it was $5 million for basically the same service. The need it to have the all weather part of what was pitched. Vertical Take-Off and Landing (VTOL) is very appealing.
2. Currently new aircraft equipment purchases/ investments do not make economic sense; therefore there are no short-term plans for one interviewee. There is a mismatch in what they can carry vs what is currently being built/talked about. In the future they anticipate investing when there is a platform that can carry payload at their current levels.
3. Another interviewee is watching the market closely and has currently made investments with other companies (i.e. autonomous Cessna Grand Caravans). While most of the projections are still uncertain, their models do show potential savings. As with everyone, they are waiting to see the actual results from these emerging technologies.
4. Currently the interviewee disclosed that they do not currently have any investments in E aircrafts. They see it as a niche and try the "wait and see" approach. Currently they fly in all sorts of weather conditions and technologies today carry half the payload at half of the range with no power for icing conditions. They are looking for more robust weather. Niche markets for these E aircrafts in warmer more urban environments like LA/San Francisco.

Key Findings:

- Currently the expected costs of implementing UAC are not economically feasible.
    - New aircraft equipment purchases/investments do not make economic sense.
    - The performance of current technologies lags the existing fleet.
        - The current fleet is more efficient in moving the required volume or cargo.
    - Currently, the UAS are not as robust as traditional aircraft and lack the ability to fly in all weather.
- The interviewees are adopting a "wait and see" approach.
- The interviewees see the highest potential for UAC in niche markets for certain technologies where weather is not an issue.

What types of new <u>airport infrastructure</u> investments purchases / investments are you anticipating will be made due to the transition from traditional to AAC (if any)? Do you have an estimate of the upfront (capital) and ongoing (operations and maintenance) costs

associated with these purchases, or held (pending orders) which will materialize when deliveries are taken?

1. They might use it as a larger reach with smaller out posts. Do more short trips with more hangars at some of the smaller locations causing new bases of operations using the road system as long as possible to shorten the flights. The security/safety of seeing what is going on at the locations.
2. Currently there are no formal steps. Currently there isn't a business case for this today. Potential future investments they anticipate include reliable electrical supply and buildings in place to keep warm, battery charging etc. In rural Alaska, reliable electricity is also challenging as most electricity is powered by diesel.
3. The interviewee is looking into XWing and other electric aircraft. The minimum infrastructure of charging stations: one at the airport and another on the property as a redundancy. The hope is that airports will invest in improvements and infrastructure, and they will pay for the services. Beta has a menu of different charging options: one slow and fast charging capabilities. While they think much will be the same, and hope for minimal airport upgrades, infrastructure must exist first.
4. The interviewee was curious where aircraft would sit to charge for vertiports. Time on the ground is money lost. Real estate availability on or near airports is expensive and limited. Funding to update the airports is also already limited; there is need to come up with a new process and develop a current business model.

Key Finding Suggestions:

- The interviewees have concerns about the costs and feasibility of implementing UAC infrastructure at airports.

As air cargo operations become uncrewed, are there airport infrastructure retrofits anticipated to be required? Please address whose responsibility you envision this will be to implement (e.g., UAS operators, airport operators).

1. Assumption would be the State of Alaska would bear the cost, but companies would be building some of the infrastructure too. Things like power would be likely the state.
2. The overall goal is to work within the current infrastructure hoping that the airports will not need many changes for uncrewed aviation. Infrastructure on the ground and procedures in the air need to be defined. When adding autonomy in the mix, there will be more scrutiny and development with the NAS. The integration with VTOL aircraft for example, is unclear to what makes it different.
3. The interviewee has not thought much about this topic again, as currently there is not a business case for this today. While there may be less crew onboard, labor may be required to handle cargo on the ground unless they are autonomous. The human infrastructure on the ground could be an issue as well (i.e. plowing of runways in rural communities). However, there are emerging technologies that the interviewee pointed out like autonomous snow removal equipment from Oslo. There is also a concern about safety.
4. No. Integration must be seamless to integrate. Work within the current structure and minimize any changes to airports. Pressure with real estate is an issue.

What do you think staffing and/or operations and maintenance would look like for vertiports?

1. It could be minimal. Some technicians but based on the machinery would be the biggest driver on what would be needed at the locations. More and more things are "maintenance free" things. Are the Vertiports the same? Like a basic standard.
2. Some concepts look way too close together to be able to load and unload cargo. The Electric Vertical Takeoff and Landing (EVTOLs) will need to change. Airports are extremely busy and will need to consider jet traffic. The interviewee is curious how EVTOLs fit in the current model and they may be different type of operations than a helicopter. Currently seeing in the engineering of vertiports many of them are transitioning aircraft into fixed wing operations. Integration of a larger scale of this with ten aircraft for example at a vertiport and then mixing it with regular traffic.
3. "No good answer on this one." Direct quote.
4. This would have to be an off-airport location: then an Uber or another service to the airport. The idea of landing in a parking lot is not likely due to limited real estate. Interviewee also brought up charging again as currently there are no charging infrastructure.

Can loading and unloading be automated? What type of infrastructure would be required to automatically move cargo to a holding/pickup location that prevents human interaction from slowing the aviation operations? What should pickup/holding look like? Is a commercial aviation baggage claim (or a similar Concepts of Operations [CONOPS]) a workable solution?

1. That is a scalability issue. In the bush of Alaska, the automation may never be cost effective. When the operations are so small and spread out like up here it is tough. In large airports in the Lower 48 it is different.
2. The biggest challenge in Alaska is controlled environment indoors. Bypass mail is the biggest driver, but even on larger hubs there are issues of items thawing. Infrastructure to build anything to scale in rural communities in Alaska is costly and challenging. While automated systems are great, maintaining them in Alaska will be challenging. The system must be robust and support the population involved.
3. Specific to EVTOL they hope to nose load the aircraft and have more automation. Most of the feeder aircraft are hand loaded and unloaded while larger operations with containers have more automation. Humans loading and unloading cargo is a hard standard to beat. Interviewee also sees limits to the EVTOL systems because they can't accept any more weight (rollers weigh too much); weight sacrifices performance. When a battery is involved, time matters even more.
4. Automated loading and unloading are difficult. If the loading component of the aircraft, it would need something to ensure no damage to the aircraft. He mentuioned the door size vs the package. Humans are still faster for much of the loading operations over a machine right now.

Key Findings:

- While automated loading/unloading is great to have, currently humans are faster and more efficient inside aircraft.

- More automation inside buildings instead of on the aircraft will be the best option for including autonomy in the loading and unloading of cargo.
- The interviewees worry that automated loading/unloading could damage aircraft.
- Rural infrastructure, especially in Alaska, is difficult to maintain or implement.

What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?

1. The interviewee would like it to be a pilot and have an interface similar to what they are already accustomed too. Simulator training will be used massively more than it has in the past too.
2. The interviewee is currently in the process of using a Remote Operating Center (ROC) with small UAS to start and working with the FAA currently with one to one operations; hoping to move to one to many operations. The vision is an agnostic ROC with agreed upon settings and peripherals in addition to a secure location for display. They want to use a small aircraft for foundational operations. Currently 400ft and below focused for lessons learned and transitioning to larger operations and must include power connectivity, redundancies in aircraft, and cooperative deconfliction. There is a need to play with each other, cooperate, and use tactical deconfliction when human factors come into play.
3. Technology is advancing, but the interviewee is watching the situation with autonomous cars with fascination. Interviewee disclosed that they are not a pilot, but thinks that within the NAS, someone with lower amount of training could control drones. An example provided included the partnership between a doctor and a physician’s assistant.
4. Interviewee sees no difference from autopilot today that is currently being used. The flight plan should be no different than any aircraft must do today.

Key Findings:

- Interviews suggest that they want interfaces that appear no different from or have significant similarities with the interfaces used by traditional systems today.
- One example to note is that someone with lower amount of training could be a controller within the NAS as long as they were supervised by a pilot in much the same way a doctor oversees a Physician's Assistant.

How can the autonomous systems be evaluated or certified such that safe integration of UAS in the existing Air Traffic Management (ATM) environment or emerging UAS Traffic Management (UTM) is enabled?

1. Demonstrating the capability. They pointed to the Google car that hit the guy on the bike. Setbacks like that need to be avoided.
2. Following basic safety management systems and meeting the same standards of crewed aircraft should make them safe to operate in the NAS.
3. The interviewee is taking an active role with this issue and is currently working with the FAA on how they should be integrated. They think AAM is going to be the driver that could help drive/shift the ATC into the future. They know how antiquated the current system is. SAGE 34, SC228. The are varying levels of autonomy that they think will have to be approached as a crawl walk run type of deal.

4. The interviewee asked how does it integrate into the current system and what is the communication methods. NASA's UTM concept will need to demonstrate performance standards. It will still need to be validated like with ADS-B.

How will new traffic management paradigms (UTM, etc) be integrated with the currently operational National Airspace System ATM?

1. They will all need reporting equipment on board some how for any of this to work. Separation was mentioned especially with different speeds and sizes. They will all need to be "seen" with some type of system. Automation of the controlling agency of an airport would need to be well proven.
2. That is beyond his tech knowledge. He doesn't have experience in traffic management.
3. Interviewee disclosed they would love to get radar feeds that are being mentioned as a start. Everyone going through zero to 400, all must cooperate. There is a concern is about the bandwidth on radios to talk to each other. Clutter is an issue and they do not want to be worried about what is going on below them that does not concern them. At or near the airports with EVTOL and small package deliveries there must be a method to turn on and off that visibility when needed. A more digital based approach is something they think might work.
4. The interviewee mentioned this is the real challenge and noted there is already a system that is being used. These vehicles would need to meet the same standards as at least helicopters for lower altitude flying. Signal mapping will be needed to stop issues with bandwidth and so on.

The interview answers and key findings provide a good assessment of where there is agreement in the air carrier community about what is needed to implement UAC and where there are gaps in knowledge or a diversity of opinions. This information will inform future research and UAC implementation.

5 GROUND AND FLIGHT TESTING

The research team designed the ground and flight testing activities included in this project to elucidate how a large UAC drone would need to be handled at an airport. The intention of the testing was to observe the turn around of a large cargo drone at an airport with limited infrastructure to try to identify what personnel, expertise, infrastructure, policies, and procedures are needed to safely land a drone coming from a different airport at an airport of interest, remove the cargo, refuel or recharge the UAC, potentially add new cargo, and take off from the airport of interest. The focus of the flight operations was not on the actual transit portion of the flight; it was on the approach to the airport through the leaving of the airport's environs. However, the transit portion of the flight did provide valuable information about how the cargo aircraft could be controlled or monitored between the airports.

At the origination and destination airports, the intention of the testing was that the A42 team would observe how the cargo drone would need to be handled after landing either at the remote airport or at the originating hub airport and propose policies and procedures for the safe handling of the drone at the airports. The team would assess everything from how the aircraft could safely taxi to a cargo loading/unloading area, to who would ensure the safety of people near the aircraft (e.g., confirming propellor shutdown, chocking wheels, etc.), to what infrastructure is needed to support the aircraft (e.g., does the aircraft need a hangar or just tie downs?, is there a spot away from the runway available for unloading and loading?, etc.) and what level of expertise is needed to unload the cargo and either replace the cargo hatches/reset the cargo delivery system, or reload the drone with new cargo, conduct a weight and balance check prior to flight, refuel or charge the drone, etc. The team also would evaluate the current infrastructure at the airport and identify what is needed to support future UAC using Light and Regional category cargo drones at both better-equipped, cargo hubs and more poorly-equipped, smaller spoke airports.

There currently are no HLR and HMR UAC drones conducting civil cargo operations at major cargo hubs in the US, so the team could not conduct those operations as a part of this project. However, there are traditional aircraft that are being converted to remotely piloted aircraft that fall in the Regional category and smaller drones being developed for the Light category that are doing pilot projects at US airports that simulate UAC missions.

The leading companies converting traditional aircraft into autonomous or remotely-piloted aircraft in the Regional category include Merlin Inc., Xwing, and Reliable Robotics. Currently, all three companies are conducting hundreds of hours of flight testing of their aircraft under Special Airworthiness Certificates in the Experimental Category (SAC-EC), usually with a safety pilot onboard the aircraft. However, in November 2023, Reliable Robotics did successfully conduct the first operations of a remotely-piloted Cessna 208B Caravan with no one onboard the aircraft in the National Airspace System (businesswire, 2023a). According to FAA (2024), a civil operator, such as these companies may apply for a "21.191 special airworthiness certificate in the experimental category for the purposes of research and development, showing compliance with regulations, crew training, exhibition, and market survey." The companies conducting flights under SAC-EC permissions cannot conduct air cargo missions for compensation, including good will; therefore, these teams are sinking significant funding into building hours on their aircraft to demonstrate their technologies are robust enough to receive a traditional type certification.

In April 2023, Xwing submitted its Project Specific Certification Plan to the FAA to become, "the first Standard Category large unmanned aerial system (UAS) to receive official project designation. This marks the beginning of the process for approval of uncrewed commercial cargo operations in the national airspace" (Commercial UAV News, 2023). Once Xwing's aircraft is type certified through this process, it can be used under a Part 135 certification and approved economic authority to conduct paid air cargo operations. Reliable Robotics' certification plan was accepted in June 2023 (businesswire, 2023a).

Until Xwing and the other teams receive type certifications, they are using funding from a variety of sources, such as FAA NextGen research grants, military small business innovation research grants, and venture capitalists, to fund the development and type certification efforts of their aircraft. For example, Xwing and UAF flew missions in the region of Hollister, California, under the FAA NextGen Crosscutting Operations Strategy and Technical Assessment grant (Medium, 2024) and Reliable Robotics flew under the FAA Urban Air Mobility Airspace Management Demonstration in the same region (businesswire, 2023b). Merlin flew autonomous Cessna 208B Caravan missions between rural airports on traditional air cargo routes in Interior Alaska during June 2023 under a FAA Test Site project (Air Cargo News, 2023). These teams are using their experience with traditional cargo operations, partnerships with certified Part 135 air carriers, such as UPS and Everts Air Cargo, and the above types of demonstrations and experiments to determine how their aircraft will be able to integrate into existing cargo routes and conduct scheduled and unscheduled operations.

One of the systems needed to conduct the integration of large cargo drones into airspace containing large numbers of non-transpondered General Aviation aircraft is Detect and Avoid (DAA), or the ability of sensors onboard the aircraft to detect other aircraft in the airspace around them and maneuver to avoid them. A certified DAA system would provide the FAA and operators with assurance that any drone will avoid a mid-air collision, but there currently are no commercially-available systems that can fill this role and the development of the systems is expensive and challenging. The lack of these systems is hindering the ability of large drones to achieve type certification and make the safety case for cargo operations.

During personal conversations over the last several years with representatives of all three companies and some of their champions (UPS, FedEx, Northern Air Cargo, etc.), Dr. Catherine F. Cahill of UAF, heard the common sentiment from the teams that it would be much better if they could carry cargo during their type certification effort to help defray the costs of the testing. From these conversations, the time it takes to achieve type certification and the funding required to go through the process appear to be two of the key facts limiting the number of companies successfully working through the process. Additionally, some of the traditional air carriers interested in the technology have expressed an unwillingness to put a lot of money into these aircraft until they are ready to conduct true air cargo operations because their profit margins are so low that they are unwilling to invest in new technology until it is proven and shown to be as a cost-effective addition to their fleet.

Building off of the team's experience with these companies, greater than 30,000 nautical miles flown out of commercial airports using Light (~300-400 lbs) category drones, and the lack of HLR and HMR UAC drones, the team focused on flight operations in the Light and Regional categories. Specifically, the team conducted a Light cargo proof of principle mission using the University of Alaska's Griffon Aerospace Outlaw SeaHunter, a 16' wingspan, 299 lbs maximum takeoff weight, twin-engine, remotely-piloted UAS (Figure 2) and observed a Regional cargo proof of principle mission using the Merlin Inc. autonomous Cessna Grand Caravan (a modified Cessna 208; Figure 3). The Merlin operation in Interior Alaska during June 2023 was funded through an FAA Test Site Broad Agency Announcement submission, not this project. However, the Merlin project provided a target of opportunity for the research team to collect observations about how an autonomous aircraft could be supported/operated in remote communities and on established cargo routes.

Figure 2. UAF's Griffon Aerospace Outlaw SeaHunter.

Figure 3. Merlin's autonomous Cessna Grand Caravan.

5.1 Flight Operations

5.1.1 Light Category Operations - SeaHunter

During the fall of 2023, the Alaska Center for UAS Integration (ACUASI) flew the SeaHunter from Fairbanks International Airport (Latitude: 64.8153544° N, Longitude:147.8566592° W; IATA: FAI; ICAO: PAFA; FAA LID: FAI; https://www.airnav.com/airport/FAI) to Nenana Municipal Airport (Latitude: 64.5473000° N, Longitude:149.0739250° W; IATA: ENN; ICAO: PANN; FAA LID: ENN; https://www.airnav.com/airport/ENN) to simulate conducting a large drone (~300 lbs) cargo flight from a large, towered airport (Class D airspace) to a smaller, non-towered airport with no cargo facilities (Class G airspace).

The UAF team, due to its status as the lead of the FAA University of Alaska UAS Test Site and the Alaska BEYOND team, possessed the required Certificates of Authorization (COA) (2021-WSA-9404 for ENN, 2022-WSA-10342 for FAI, and 2022-WSA-10406 for the path between FAI and ENN) required to fly their Light category SeaHunter drones from FAI approximately 40 miles to ENN, land, and then fly back to FAI (Figure 4). The drone was accompanied by a chase plane to ensure the safety of the operation and the routing took the drone away from the primary flight path used by General Aviation over the Tanana River between the airports. Along the flight path, there was a hand off of aircraft command and control from one ground control station to another. By having a remote pilot in command in the target community, the team demonstrated one potential way for ensuring the safety of the airspace and airport by having someone watch the drone as it lands in the community. It does require that a trained remote pilot in command be stationed in the community, so it is not the preferred method for air cargo carriers trying to make their systems operate cheaply (e.g., without placing or hiring a local pilot in the community); the preferred method is to do the entire flight from a single ground control station. However, since this was a pilot project, the team wanted to ensure that there was minimal chance of losing command and control links near the airport environs by using a second ground control station at ENN.

The responsibilities of the teams at the two airports were as follows:

The combined teams conducted a flight briefing prior to deploying to their operational locations.

The team on the ground at FAI:

- Prepared the aircraft for flight;
- Followed the Pre-Flight checklist ;
- Taxied the aircraft to the General Aviation runway;
- Conducted the take-off from FAI;
- Flew the SeaHunter from Fairbanks through the switch of flight operations to the ENN team near the halfway point;
- Watched the landing at ENN via the FAI Ground Control Station (GCS);
- Followed the take-off from ENN back to FAI;
- Took control of the aircraft near the halfway point;
- Landed the aircraft back at Fairbanks; and
- Taxied to the start point at the GCS.

Unmanned Aircraft System COA
Public Agency
2022-WSA-10406-COA

Page 8 of 8

Attachment 1

Operations Area

Class D, E, and G Airspace
At or below 7,000 feet AGL

Area FAI-ENN Route Points

Latitude	Longitude
64°45'19"N	148°0'2"W
64°37'40"N	148°8'38"W
64°34'6"N	148°46'8"W
64°31'55"N	148°45'57"W
64°35'54"N	148°5'34"W

Figure 4. The flight path allowed between FAI and ENN under COA 2022-WSA-10406.

The team on the ground at ENN:

- Setup to track the flight in parallel to with the FAI team;
- Conducted their own Pre-Flight checklist;
- Tracked the take-off at FAI;
- Took control of SeaHunter during the switch between GCSs near the halfway point;
- Landed the aircraft at ENN;
- Prepared the aircraft for the flight back to FAI;
- Lead the take-off at ENN;
- Switched operational control to the ENN team at the halfway point; and
- Followed the landing back at Fairbanks via their own GCS.

The SeaHunter conducted its first successful flight between FAI and ENN on Aug 2, 2023. The hand-off between GCS at FAI and ENN in the middle of the flight, near the elbow of the flight path, went well and the aircraft landed successfully in ENN. Before the team could repeat the flight from FAI to ENN and the return flight to FAI, questions about where the GCS was located at ENN and what permitting was required beyond the approval of the airport manager to be at that location delayed the operations by a month. The team and FAA resolved all of the questions through discussion with multiple lines of business in the FAA and submitted FAA Form 7460 (Notice of Proposed Construction or Alteration) to allow their GCS to be placed in the Taxiway Safety Area. The GCS needed to be in the Taxiway Safety Area since the Runway Object Free Area (ROFA) was not cleared and the team needed radio line of sight for ground operations. The taxiway was closed during operations to ensure safety and a ground Notice to Air Mission (NOTAM) was implemented before operations commenced. UAF then resumed operations.

The team successfully completed the FAI-ENN flight on Sept. 7, 2023 (Figures 5 and 6) and the FAI-ENN-FAI flight Sept. 8, 2023. The team collected information on what infrastructure and personnel support were required to receive the aircraft, unload it, reload it, prepare it for flight, and launch it at a Class G airport with minimal infrastructure. This case also demonstrated a potential use case with a remote pilot and visual observer being available in the community to safely land the aircraft at the airport and ensure the runway is clear of people and obstructions prior to landing.

Figure 5. SeaHunter underway between FAI and ENN. Photo courtesy of Peter Houlihan.

Figure 6. SeaHunter preparing to take off at FAI on September 7, 2023.

5.1.2 Regional Category Operations - Merlin

Merlin Inc. flew a converted Cessna Grand Caravan, a Regional category-sized aircraft, equipped with an autonomous pilot capability between the Everts Air Cargo Facility at Fairbanks International Airport (FAI) and the remote communities of Deadhorse, Ft. Yukon, Galena, Huslia, and Tanana (Figure 7) as a part of a FAA University of Alaska UAS Test Site project (FAA Contract 697DCK-22C-00261M and activities described in Merlin, 2023). Merlin operated their converted Cessna Grand Caravan on a Special Airworthiness Certificate - Experimental Category for the aircraft and had a safety pilot and other personnel, including software engineers, onboard the aircraft to ensure safety. The project's goal was to gather quantitative and qualitative data on the feasibility and challenges of operating an advanced aviation system in the NAS, specifically along established cargo routes in Alaska's interior, but it allowed the research team personnel to observe the landing and operations at the remote communities. The researchers watched the operations with an eye to determine what support infrastructure and personnel support are required to receive the aircraft, unload it, reload it, prepare it for flight, and launch it and how these needs vary based on airport location and community size.

Figure 7. The location of Fairbanks and the five other communities Merlin flew between during this project.

The Merlin team completed 25 flights in total for a total of 66 flight hours under a wide variety of airspace, runway, and weather conditions. The Cessna landed on paved and gravel runways and routed itself around clouds to maintain the Visual Flight Rules limited required by its Special Airworthiness Certificate. In addition, the Merlin team collected information on how many radio communications the aircraft received from all sources, how many of them were directed at the aircraft, and how many required pilot or aircraft responses. The Merlin Natural Language Processing system was able to receive and correctly respond to most voice commands from ATC. The aircraft's response to ATC commands is essential for the safe operation of the autonomous aircraft during flight and ground maneuvers.

5.2 Flight Operations Applicability to Research Questions

5.2.1 Light Category Operations - SeaHunter

The research team conducting the FAI to ENN and back operations had the following observations about what is needed to implement remotely-piloted UAC at these airports. The team grouped their observations according to the applicable research questions listed above.

1. "Understand trends in large UAS, particularly with a focus to understand its role in cargo delivery, both scheduled and unscheduled routine operations."

- There is a current need to identify ground support elements in isolated communities and areas of operation where an UAS utilizes the typical crew complement to assist in ground duties to include fueling, unloading, loading, preflight inspections, and general ground support elements.
- As it relates to ground duties, a typical "GCS to GCS Handover" presents an economically viable means of fueling assistance, preflight, and general ground support; however this significantly limits the overall usefulness of a system capable of conducting landings at unscheduled landing locations (e.g., an in-air divert to a different station due to weather). In the flight testing conducted, ground crews were available to deal with situations that were presented at either intended landing site and weather minimums were strictly adhered to in order to prevent an in-air divert becoming a reality. This poses many questions when approaching the idea of scheduled and unscheduled operations.
- The flight testing that was conducted followed visual flight rules, with the caveat of minimum fuel requirements. Due to the nature of the system and required lost comms procedures, researchers elected to carry an excess of fuel more closely resembling instrument flight rules fuel minimums. That amount of fuel is nowhere near the theoretical limit of fuel that would be able to scale with the SeaHunter platform. This may not track as closely when scaling to larger air frames, however consideration should be given to looking into fuel planning for UAS in the NAS. Based on our flight testing during this recent flight period this problem was not present due to regulatory limitations of chase plane operations and weather minimums.
- Unmanned Aircraft Vehicles (UAVs) present the unique capability of more closely integrating with more autonomous systems to include in-air refueling and ground based autonomous refueling.

2. "Establish likely relationships between likely manned cargo transitioning into unmanned large UAS."

- Based on current regulation items relating to the logging of Pilot in Command (PIC) and Second in Command/Navigator/Operator time for UAS will need to be improved. Removing any barriers to this and codifying a standard and allowing for transition between both Civilian and Military UAS would prove beneficial to strengthening the transition period for all operators between any aircraft, not just UAS.
  - To the above, the transition from current crewed and uncrewed platforms would benefit from a standardized training pathway, similar to how the current Part 107 test resembles the private pilot license written. However this process does not scale

with large UAS operations, due to the gap in knowledge covered between the Part 107 and standard ACS/Written testing standards.

- Based on flight testing, there is massive crossover between the current ATM system and UAS interactions, especially in areas that require Mode C, Transponders, ADS-B and other required reporting equipment. Based on conversations and debriefing held with controllers at PAFA, there is very little difference between a large UAS and a typical aircraft. Remotely piloted aircraft can respond to controllers in the same way any typical air traffic would as it related to crewed cargo platforms, even in areas with significantly less infrastructure than typical cargo hubs. This tracks with previous flight testing ACUASI has performed in the past and previous debriefs with different controllers. In the case of a large UAS, the ability to transmit the same level of data being sent to controllers allows for relatively seamless changes in the current ATM system.
- Based on current infrastructure available at large cargo hubs, the transition to a mixed crewed/uncrewed environment would require increased awareness of UAS operations, however in controlled airspace especially ,the differences would boil down to the level of DAA equipment on board. For example, establishing standards that mimic current "well-clear" requirements for all air traffic and holding UAS to that similar standard in a mixed environment.
- Based on recent flight testing, many of the relationships to transitioning to a more uncrewed environment come down to the airport environment itself. Radio Line of Sight becomes significantly more important when aircraft are operating on frequencies that require it. Some airport environments may not easily accommodate this style of operation depending on the Command and Control (C2) of the given platform. Consideration should be given to this when discussing future airport planning.

3. "***Establish any significant change following the onset of COVID-19 and likely adoption of larger UAS in cargo carrying capabilities."***

- The opportunities presented following the onset of COVID-19 proved to be a boon for potential large UAS operations. The advantages of a "zero human contact" UAS could prove to be a massive advantage to life saving deliveries and critical transplant flights. These flights risk being delayed due to concerns about spreading a similar epidemic. The desire for both small and large UAS in the medical field has increased drastically. Native, Local, and State government support has been at an all time high to get this technology fielded, not to mention the overwhelming support from the general population for this style of operation as it relates to medical flights. A whole paper could be devoted to the applications in this field alone, and as it relates to larger UAS it is the logical next step forward for more logistically challenging medical issues, to include COVID-19.

4. "Forecast large UAS, both civil and commercial, and transitioning sUAS requiring analysis of market including competition, technology, and the anticipated trajectories into nonsegregated airspaces together with anticipated timelines."

- The key limiting factor at this time from an economic standpoint is a well defined, tested and proven method of DAA. This was proven in flight testing by the inclusion of flying into nonsegregated airspace and areas without significant radar coverage. SeaHunter's flight into a non-towered airport with a chase plane proves this point. At this time, a combination of research and technology is needed in order to complete that level of finite analysis as it relates to large UAS operations. It is worth noting that on large platforms in the 1000+ Gross weight region could accommodate more resource intensive methods of conducting this type of DAA, but that is out of scope for this current round of testing and further comment would require further testing. The anticipated trajectory of the industry as a whole hinges on this key component and in some ways mimics development of the NAS itself.

5. "***Understand performance characteristics, reliability and standards of large UAS and those sUAS anticipated to transition within the ATC-serviced airspaces (G, D, E, A, B, and C in probable order of importance) over the next few years."***

- Based on the most recent flight tests, it is apparent that the overlap in performance standards as it relates to transponders is of the utmost importance, excluding remote identification. Maintenance standards to be included from a reliability standpoint should also be included and a well defined acceptable C2 link. The closer these performance standards mimic that of crewed aviation the smoother the transition period and more overlap these systems can have. It is important to understand some of the fundamental differences that a large UAS may have when compared to a more conventional crewed platform; however these items pale in comparison to the overall objective of safety and there are far more comparable similarities than differences when referencing large UAS. The ACUASI test platform used for these flights is treated to the greatest extent possible as a typical crewed platform, with normal maintenance intervals, testing requirements, and transponder and pitot static testing being to the same exacting standards as any other platform. This level of confidence may not always be required for every UAS operation, in particular those operating in sparsely populated areas or those conducted for research in truly remote regions, but in more congested A, B, C and D airspace, this test flight revealed as in previous flights that holding a large UAS to identical or similar standards proved acceptable.

6. "***Understand performance requirements of ATC to allow large UAS to be flying in the airspaces e.g., under what circumstances, can these large UAS fly within the Mode-C veils?"***

- See previous answer. Short answer to the given example: hold the large UAS to the same standard of required transmitting equipment as aircraft already in that airspace. And understand the need to determine more robust airborne DAA solutions.

7. "***Understand separation requirements and/or rules for integration (i.e., communication, navigation, surveillance, informational (i.e., CNSi) rules, in particular) into these airspaces."***

- Continued research into many of these topics is required, at this time the overall confidence is low as it relates to communication. See previous responses for those relating to navigation, surveillance. Determining defined UAS frequencies for C2, and communication.

8. Provide an understanding of physical infrastructure required to facilitate large UAS delivering cargo incrementally in the NAS, e.g., redesigning of airport including ramps, delivery points, etc."

- See previous responses.

5.2.2 Regional Category Operations - Merlin

The research team grouped their observations of Merlin's operations according to the applicable research questions listed above.

1. "Understand trends in large UAS, particularly with a focus to understand its role in cargo delivery, both scheduled and unscheduled routine operations."

- The Merlin aircraft demonstrates a trend in large UAS where companies are converting traditional aircraft already used for cargo deliveries in much of the US to remotely piloted or autonomous UAS for cargo operations. Xwing and Reliable Robotics are two other examples of this trend. The expectations of these companies is they will be able to fly existing routes and conduct both scheduled and unscheduled routine operations. This is what Merlin demonstrated in this flight campaign. They flew existing cargo routes and used existing infrastructure.

2. "Establish likely relationships between likely manned cargo transitioning into unmanned large UAS."

- Merlin is an example of how some of the first manned cargo operations might transition into unmanned large UAS operations. The flight operations were almost exactly the same as for the manned cargo operations as far as ATC and other airspace users were concerned. These manned aircraft conversions are designed to use existing infrastructure so there will be less upfront infrastructure investment to implement this technology at airports.

3. "***Establish any significant change following the onset of COVID-19 and likely adoption of larger UAS in cargo carrying capabilities."***

- The Merlin aircraft demonstrated that a large drone could deliver current quantities of cargo that are already being delivered by Cessna Grand Caravans without sending a potentially infected human pilot into a community. Whoever does the loading would need to be trained in weight and balance at a minimum for the aircraft to be used or the aircraft itself could have sensors not allowing it to take off out of limits of its weight and balance. However, if this aircraft was fully type certified during the COVID-19 pandemic, it would have been the best option for Regional-category deliveries across Alaska and the US.

4. "Forecast large UAS, both civil and commercial, and transitioning sUAS requiring analysis of market including competition, technology, and the anticipated trajectories into nonsegregated airspaces together with anticipated timelines."

- The key limiting factors for implementing the Merlin technology at this time are the time and technologies required to get the aircraft fully type certified, including with a sufficient DAA system to allow the aircraft to fly with all of the non-cooperative General Aviation operators, such as those seen during this flight testing in non-segregated airspace.

5. "***Understand performance characteristics, reliability and standards of large UAS and those sUAS anticipated to transition within the ATC-serviced airspaces (G, D, E, A, B, and C in probable order of importance) over the next few years."***

- The Merlin aircraft operated effectively in G, D, and E airspaces with ATC services during their flight campaigns. The Merlin research described in their final report for their FAA Test Site operations (Merlin, 2023) shows some of the performance characteristics, reliability, and standards that will be needed to fully integrate this technology into the NAS. For the autonomous Cessna-type systems the needs include standards for language processing for autonomous systems to engage with ATC, sufficient weather information for the aircraft to make routing decisions, standard manned Cessna maintenance, and operational requirements, plus additional standards for autopilot reliability, situational awareness for ground operations, sufficient DAA capabilities, etc.

6. "***Understand performance requirements of ATC to allow large UAS to be flying in the airspaces; e.g., under what circumstances, can these large UAS fly within the Mode-C veils?"***

- The Merlin aircraft should have the same performance requirements as aircraft already in that airspace with additional requirements for DAA and ADS-B in and out within the Mode-C veils where all aircraft should be communicative.

7. "***Understand separation requirements and/or rules for integration (i.e., communication, navigation, surveillance, informational (i.e., CNSi) rules, in particular) into these airspaces."***

- The Merlin aircraft should be able to perform as a manned aircraft in most of these airspaces, so the current separation requirements and rules for integration should hold.

8. "Provide an understanding of physical infrastructure required to facilitate large UAS delivering cargo incrementally in the NAS, e.g., redesigning of airport including ramps, delivery points, etc."

- The Merlin aircraft does not require the redesign of physical infrastructure for conducting cargo operations in the NAS. From the research team's observations, it could operate effectively on paved and gravel runways and the aircraft does not require specialized loading and unloading equipment if the loading is done by a knowledgeable cargo handler who understands weight and balance.

9. "What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?"

- The interface should look similar to a mix of what a pilot sees in an aircraft and what an ATC person sees in a control tower. The systems should be standardized to have a minimum equipment list too.

10. "How will the UTM paradigm integrate into the large UAS environment? Or will a separate paradigm be required? How will these traffic management paradigms be integrated with the NAS ATM that is already operational?"

- The NAS ATM should be viewed as an integrated whole and all participants in the NAS should be communicating. That would make the Merlin aircraft a simple integration into the existing NAS ATM system because it is large, transpondered, and acts like any other aircraft in the NAS. This is what the flight tests showed; the Merlin aircraft behaved like any other aircraft as far as ATC was concerned. UTM appears to be a separate 400ft and below airspace tracking system that requires infrastructure not available in large portions of Alaska and more rural regions of the rest of the US and does not appear appropriate for these larger UAS that are capable of acting as a traditional aircraft under the current NAS ATM infrastructure.

5.3 Flight Operations Lessons Learned

- An airport's not clearing of the trees in the Runway Safety Area or ROFA can inhibit drone operations at an airport.
- Just because an airport manager gives permission for a ground control station trailer to be located adjacent to a runway is not sufficient to meet FAA recommendations/regulations.
  - Ground NOTAMs must be issued in addition to airspace NOTAMs.
  - Ground control station is considered construction equipment and requires associated paperwork to be adjacent to a taxiway.
- The process for operating a large drone at an airport is not clear. The team can get different responses from different FAA Lines of Business. A key factor in conducting operations is determining who has authority as opposed to who can only make recommendations.
- Community outreach to towns/village/cities and to communities of practice (General Aviation and commercial aviation) will be essential for the acceptance of drones flying large cargo or regional air mobility.
  - People could not believe the Cessna was the 'drone' that they heard was coming.
  - Many pilots called the Merlin team on the radio in flight to ask if they (Charlie Bravo) were the drone and ask questions.
    - Consensus from the pilots was that the autonomous Cessna was cool.
- Researchers do not know what problems they will encounter until they conduct tests.
  - Communicating with the fuel provider in Galena was a challenge.

6 ECONOMIC ASSESSMENT

Air cargo plays a critical role in the globalization and evolution of supply chains by allowing geographically dispersed and distant markets to be intricately linked for production and consumption. As the air cargo industry transitions to advanced air mobility, it is anticipated that new markets will emerge, and existing marketplaces will gain efficiency and volume.

To understand the extent of the domestic AAM air cargo market, an Economic Assessment (Task 5) was undertaken to evaluate the economic impact of AAM Cargo from 2024 to 2045. The assessment quantifies the economic impacts stemming from three primary drivers of AAM cargo economic activity. These drivers include:

- AAM cargo market flight activities (how much revenue will be generated by transporting air cargo),
- Fleet investments (how many advanced aircraft will be purchased, or existing aircraft will be retrofitted with advanced capabilities to meet AAM cargo market demand, and what expenditures will be required to maintain them), and
- Ground infrastructure activities (what types of infrastructure investments will be required to transition from traditional air cargo to advanced air cargo and what expenditures will be required to maintain ground infrastructure).

Prior to the Economic Assessment, a comprehensive literature review (Task 1-1) followed by an AAM Cargo Market Analysis (Task 1-2) and Designed Experiments (Tasks 3 and 4) were conducted. Altogether, these interim research deliverables provided an up-to-date accounting on the transition to AAM cargo, its effect on the US economy, and helped address many of the foundational questions that motivated this research. Findings from these deliverables are extracted or summarized and included within the Economic Assessment. This was done intentionally to allow the reader ease of access to content related to the specific research questions.

The Economic Assessment also contains both updated and new content within the “Potential Size and Growth of the Air Cargo Market” and the “Economic Impact of AAM Cargo” based on research undertaken since the completion of Tasks 1-1 and 1-2. The Economic Assessment is organized thematically by the questions guiding the research, which are shown in

. Designed as a navigational guide, the table lists both the research questions and the sections within the Economic Assessment where they are discussed.

Table 2. Research Questions.

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
Overarching Research Questions		
What is the potential for large UAS in carrying air cargo in the US?	Yes	Potential Size and Growth of the Air Cargo Market
What is the likely effect of pandemics such as COVID-19 on adoption of larger UAS in cargo carrying?	Yes	COVID-19 Related Impacts on Air Cargo Markets
What is the likely location and distribution of large UAS to meet demand and growth of air cargo over a period of 10 years?	Yes	Potential Size and Growth of the Air Cargo Market
What interface characteristics are necessary for the UAS pilot (IPP), existing and emerging businesses (e.g., package delivery under Part 135 and/or waiver trends) or UAS passenger (e.g., UAM) to maintain awareness of aircraft system state with automated aircraft system and subsystem control?		

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?		
How can the autonomous systems be evaluated or certified such that safe integration of UAS in the existing ATM environment or emerging UTM is enabled?		
How will the UTM paradigm integrate into the large UAS environment? Or will a separate paradigm be required? How these traffic management paradigms be integrated with the NAS ATM that is already operational?		
How will strategic scheduling of large UAS occur?		
How will the non-scheduled large UAS be handled?		

<table>
<tr><th>Research Question</th><th>Discussed In Economic Assessment</th><th>Section Where Question is Addressed</th></tr>
<tr><td>What other resources and NAS investment may be necessary to facilitate growth of UAS in air cargo?</td><td>Yes</td><td>
Air cargo is a key enabler of global trade and an essential mode of transport for high-value commodities. Though air cargo is responsible for transporting less than one percent of global trade by volume, its share accounts for 35 percent of global trade by value (IATA, 2017). This equates to transporting approximately 657 million packages worth $17.8 billion are transported in a single day, or $6 trillion worth of goods annually (IATA, 2017).
As demand continues to grow, it is anticipated that advanced air cargo will fulfill an increasing share of cargo transport over time. Though the advanced air cargo market is currently in its nascent stages, the next stage of industry development is expected to occur from 2022-2025 (Kovalev et al., 2019). During this stage, the US and the world will begin to see large-scale applications of UAS for commercial purposes and the expansion of their functionality. Thereafter, unmanned cargo transport is projected to gradually become more and more mainstream (Kovalev et al., 2019).
Despite the optimistic signals for air cargo growth, the industry is highly competitive. As businesses determine their methods for transporting goods, cost and delivery speed are often the dominant factors (Kloss & Riedel, 2021). As such, competition for AAC services, is highly dependent on the transport mechanics of each of the four air cargo market segments: HLR, HMR, Regional, and Light. HLR and HMR aircraft are generally used to transport either high-cost or time-sensitive goods overseas or from coast to coast. The primary competition for these use cases comes from ocean freight, trucking, and intermodal shipping. Regional aircraft are anticipated to continue servicing feeder markets, while light could potentially serve where VTOL infrastructure emerges. Both regional and light aircraft use cases will compete with trucking. A summary of air cargo market segments and their primary competitors is shown in Table 6.
Table 6. Air Cargo Market Segments and Their Primary Competitors.
<table>
<tr><th colspan="3">Heavy / Long Range (HLR) | Market and Competition</th></tr>
<tr><td>Mission Range: > 3,000 nautical miles
Payload: > 40 tons
Speed: 400-500 knots</td><td>Primary Niche / Market
• Transoceanic Flight
• Transport imports / exports
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Sea / Ocean Freight</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Research Question</th><th>Discussed In Economic Assessment</th><th>Section Where Question is Addressed</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th colspan="3">Heavy / Medium Range (HMR) | Market and Competition</th></tr>
<tr><td>Mission Range: 500-3000 nautical miles
Payload: > 10 tons
Speed: 350-500 knots</td><td>Primary Niche / Market
• Domestic & Transoceanic Flight
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Trucking / Intermodal Shipping
• Sea / Ocean Freight</td></tr>
<tr><th colspan="3">Regional (Feeder) Aircraft | Market and Competition</th></tr>
<tr><td>Mission Range: 75-1,000 nautical miles
Payload: 1-10 tons
Speed: 150-300 knots</td><td>Primary Niche / Market
• Regional Flight
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Truck / Intermodal Shipping</td></tr>
<tr><th colspan="3">Light (VTOL) Aircraft | Market and Competition</th></tr>
<tr><td>Mission Range: <250 nautical miles
Payload: 50-2,000 pounds
Speed: <200 knots</td><td>Primary Niche / Market
• Local & Regional Flight
• Transport time-sensitive goods
• May be low, medium, high cost</td><td>Primary Competitors
• Trucking / Express Carriers</td></tr>
</table>

Enabling Infrastructure</td></tr>
<tr><td>What will be the aggregated economic benefits, i.e., direct, indirect and induced, of integrating large UAS in transporting air cargo on the overall economy?</td><td>Yes</td><td></td></tr>
<tr><td colspan="3">Questions Motivated by AAM Air Cargo Economic and Market Research</td></tr>
<tr><td>Potential size and growth of the air cargo market at the local and at national level;</td><td>Yes</td><td>Economic Impact of AAM Cargo</td></tr>
</table>

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
Economic feasibility including price points and competitive alternative (e.g., traditional delivery by trucks; existing manned air cargo) at which individual market becomes viable;	Yes	Competition for AAM Cargo Services; Potential Size and Growth of the Air Cargo Market
Effect of pandemics, such as COVID-19, on the adoption of larger UAS in cargo carrying operations;	Yes	COVID-19 Related Impacts on Air Cargo Markets
Anticipated cost to enter the market, considering factors such as vehicle acquisition and life cycle, operation liability, maintenance and replacement and upgrade schedules;		Costs to Enter the Market
Customer segments (e.g. warehouses, business locations, residential nodes, etc.) for UAS viability in air cargo;	Yes	Market Segments; Inertia enabled by airport infrastructure, warehousing, logistics centers, population density, and the existing hub and spoke aviation networks will continue to attract air cargo activities to existing markets. However, the emergence of AAM technologies will also unlock new air cargo markets that were previously not feasible. **6.1.1.1 Site Suitability Analysis – Characteristics Favorable for New AAM Cargo Markets** General aviation airports are expected to play a crucial role in the transition to AAM air cargo, serving as gateways for new market activity. The existence of runway infrastructure, surface transportation connections, lower-density airspace, and available space for electric charging

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
		stations and power retrofits are cited as important infrastructure for AAM activities (McKinsey & Company 2023; NREL 2023; InterVISTAS 2021; NASA 2021). Though the AAM cargo landscape is still largely in development, AAM air cargo's comparative advantage is expected to exist within areas that are difficult or costly to reach by truck or other surface transportation. This includes areas with rugged topography and/or minimal connections to freight networks. Unlike heavy long range or heavy medium range air cargo use cases that require large runways found within hub and spoke airport networks, light and regional air cargo use cases enlist aircraft that are smaller, more agile, and can be serviced by a greater array of landing infrastructure. For example, aircraft within the light use case require runway lengths as little as 100 to 300 feet, meaning that existing open spaces and rooftops of warehouses or large buildings could serve as potential "runway" candidates (InterVISTAS, 2023). Meanwhile, aircraft within the Regional use case are typically serviced by runway lengths of 4,800 feet or less, as shown in Table 10. Though runway length is an important limiting factor for AAM cargo activity, there are a number of important site-selection variables that can help determine the most suitable locations for AAM cargo markets. As an integral part of this research, a site suitability analysis was conducted to gauge where AAM air cargo market development is most likely to occur in within the United States. To fully understand the most suitable locations for AAM passenger services, the research team reviewed more than 100 peer-reviewed journal articles, market reports, industry papers, and regulatory briefings. The literature review (Task 1-1) and Market Analysis (Task 1-2) led to the determination of 10 variables that affect AAM air cargo growth within new markets, as shown in Table 120.

Table 10. Regional Use Case Runway Characteristics (Adapted from Crown Consulting, 2021).

Regional Aircraft	Runway Length in Feet	Explanation
Cessna Turbo Stationair HD Cargo	1,970	**Grouping: 1,970'-3,000'**
Cessna Caravan	2,055	

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed

Cessna Grand Caravan EX	2,160	Services 33 percent of aircraft documented in the use case
ATR 42	2,600	
Fairchild Metro II	3,000	
Beech 99	3,200	**Grouping: 3,001'-3,600’** Services 73 percent of aircraft documented in the use case
Beech 99	3,200	
Beech 1900	3,470	
Fairchild Metro III Heavy	3,500	
Bombardier Q300 (Dash 8)	3,600	
Bombardier Q300 (Dash 8)	3,600	
Cessna SkyCourier	3,660	**Grouping: 3,601’+** Services the remaining aircraft documented in the use case
Saab 340B	4,300	
ATR 72	4,315	
Saab 340B	4,800	

Table 11. Light Aircraft Ranges and Payloads (Crown Consulting, 2021).

Light Aircraft	Range	Payload	One-Way Distance
Ehang 216 (logistics)	22 miles	440 lbs	11-17 miles
Volocopter VoloDrone	25 miles	440 lbs	
Volocopter Velocity	31 miles	2 pax with luggage	
Bell Apt 70	35 miles	70 lbs	
Airbus CityAirbus	50 miles	4 pax (550 lbs)	25-75 miles
Bell Nexus (4EX)	60 miles	4 pax, 1 pilot, w/ luggage	
Vertical Aerospace VA-1X	100 miles	1 pilot and 4 pax (992 lbs)	

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed

Kitty Hawk HVSD	100 miles	No data	
Bell Nextus (6HX)	150 miles	4 pax, 1 pilot, w/ luggage	
Joby S4	150 miles	4 pax, 1 pilot	
Lilium Jet (5-seat)	186 miles	5 people	93-150 miles
Pipistrel Nuuva V300	186 miles	1,014 lbs	
Airflow Aero STOL	250 miles	500 lbs	
Elroy Air	300 miles	300-500 lbs	

Serving as essential gateways for the transport of air cargo, airports were selected as the geographic unit of analysis to identify which budding markets would be most suitable for AAM cargo. During the transition from traditional to AAM air cargo (estimated to be the 2024-2045 time horizon), it is anticipated that airports will serve a vital role facilitating AAM air cargo market penetration. As existing air cargo markets are primarily fulfilled via hub-to-spoke aviation coinciding with ground infrastructure connections, it is anticipated that new air cargo markets will fulfill spoke-to-spoke, or spoke-to-last-mile deliveries that were not economically feasible prior to AAM capabilities.

With airports serving as the unit of analysis for the site suitability analysis, it is important that results are interpreted correctly. Ultimately site suitability analysis provides a ranking of airports based on the extent to which they would be suitable for emerging regional and light AAM air cargo markets (existing air cargo markets that are typically driven by HMR, HLR, and regional hub-and-spoke operations are not the focus of this analysis). The suitability analysis assumes that airports equipped with key enabling infrastructure could likely be used as "gateway" locations to transfer air cargo from regional aircraft to Light aircraft that would then complete the final delivery of cargo to warehouses, distribution centers, community centers, or other accessible locations within the feasible light aircraft flight ranges.

To illustrate the "gateway" concept airports within the state of Alaska are used as an example as shown in Figure 1212. Within Figure 1212, Alaskan airports are categorized within three

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
		groupings. Blue airports have runway lengths ranging from 1,970-3,000 feet, red airports have runways with 3,001-3,600 feet, and red airports have runway lengths greater than 3,600 feet. With all other factors held constant it can be reasoned that red airports are the most suitable for AAM cargo operations because they can service more than 73 percent of the aircraft within the regional use case (see Table 10 for a list of regional aircraft and their associated runway lengths requirements). This example provides a simplified illustration of how to determine market suitability.

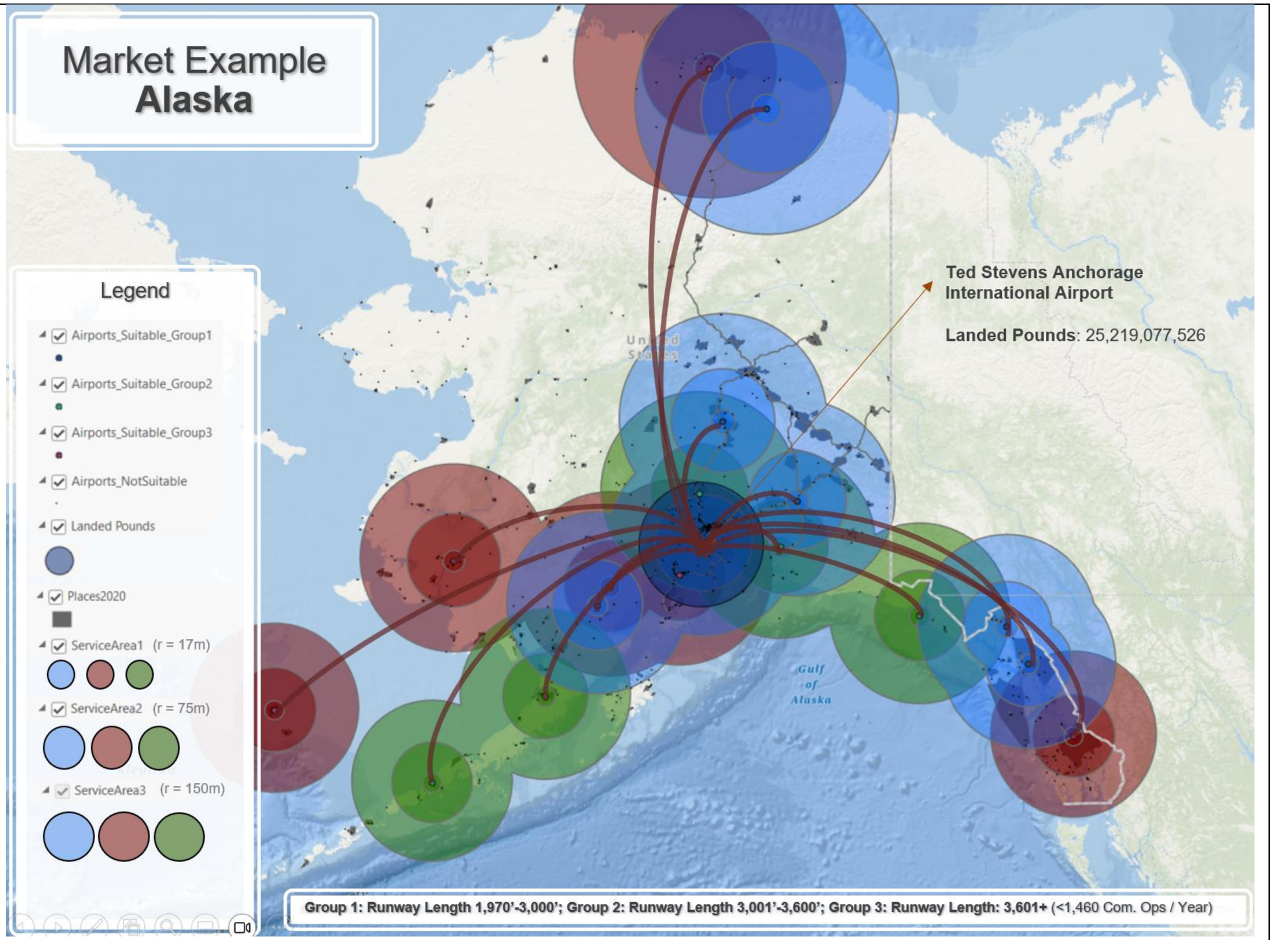


Figure 12. Site Suitability Analysis – Demonstration of AAM "Gateway" Concept.

For this research, a full site-suitability analysis was undertaken to score and rank a universe of 19,782 airports within the United States (list includes all NPIAS airports as well as other public and private airports based on their suitability for regional and light air cargo operations. After a comprehensive literature review and market analysis, 10 variables were selected. The values used within the site suitability analysis and their evaluation criteria are documented below. As an important note, a site suitability analysis workbook tool was developed to coincide with this

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
		research. The workbook tool offers default values recommended by the research team. However, the tool also allows users to adjust the weights of a site suitability variable, which in turn affects the rankings of suitable airports. **Site Suitability Analysis Evaluation Criteria** ***Fuel Sales.*** Airports have been classified into three categories based on fuel sales: those that serve Jet A fuel types, those that only serve other non-A fuel types, and those that with no access to fuel. A weight of 2 is applied to airports that sell Jet-A fuel, a weight of 1 is applied to airports that sell fuel other than Jet-A, and airports not serving fuel receive a weight of 0. ***Runway Length.*** Airports have been classified into three categories based on runway length. Airports containing runways within the range of 1,500-3,000 feet receive a weight of 1, airports with runways within the range of 3,001 to 3,600 receive a weight of 2, and airports with runways greater than the 3,601-foot threshold receive a weight of 3. ***Commercial Service Interference.*** Airports with annual commercial operations below the threshold value of 1,460 annual commercial operations receive full credit for this variable. Airports with annual commercial operations above the threshold value receive gradually decreasing credit based on a ratio of their commercial operations to the threshold value. (The threshold value is adjustable within the workbook tool.) ***Count of Proximate Substations.*** Airports with as many or more substations within 10 miles as the threshold value (4 substations within 10 miles) receive full credit for this variable. Airports with fewer substations within 10 miles than the threshold value receive gradually decreasing credit based on the ratio of their substation count to the threshold value. (The threshold value is adjustable within the workbook tool.) ***Proximate Population Count.*** Airports with equal or more population within 11 miles as the threshold value (5,000 individuals) receive full credit for this variable. Airports with less population within 11 miles than the threshold value receive gradually decreasing credit based on

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
		the ratio of their population total to the threshold value. (The threshold value is adjustable within the workbook tool.) ***Freight Connections.*** Airports with an equal number or fewer freight connections than the threshold value (0 connections to the freight network) receive full credit for this variable. Airports with more freight connections than the threshold value receive gradually decreasing credit based on the ratio of their freight connections to the threshold value. (The threshold value is adjustable within the workbook tool.) ***Terrain Ruggedness.*** Airports with terrain ruggedness at or above the threshold value receive full credit for this variable. Airports with terrain ruggedness below the threshold value (240m: Moderately Rugged [Extreme Appalachians, Moderate Rockies]) receive gradually decreasing credit based on the ratio of their terrain ruggedness to the threshold value. Four terrain ruggedness selections can be made within the workbook tool – 117m: Slightly Rugged (Foothills, Rolling Hills, Hill Country), 162m: Intermediately Rugged (Moderate Appalachians), 240m: Moderately Rugged (Extreme Appalachians, Moderate Rockies), 498m: Highly Rugged (Extreme Rockies). ***Existing Investment.*** Airports can be given different values for existing investment based on the state in which they are located. Weights applied in this table reflect assumptions of the relative advantage of airports based on their state's investment. For example, a value of 1.5 assumes a 50% advantage over a value of 1. The research team used the Simple Multi-Attribute Rating Technique (SMART) to develop suitability scores for the universe of 19,782 public and private airports in the United States. Using this approach, each airport was given a final score using the weighted average of standardized market condition attributes. Weights assigned using the SMART model reflect the relative importance of each variable to the decision-maker. The research team calibrated variable weights by emphasizing market characteristics of AAM air cargo for regional and light use cases. The final set of variables and weights is shown in Table 12.

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
		The site suitability analysis is a first step to gauge where conditions for new AAM air cargo markets are most favorable in the US. Analysis results are shown in Table 13.
Characteristics of population density, traffic patterns including radius of feasible logistics, affordability, and preferred locations for cargo hubbing (i.e., defined network) vis-à-vis point-to-point deliveries (i.e., open delivery network);	Yes	Market Characteristics and Viability
Characteristics of resulting network: defined network (i.e., delivery between defined end points such as warehouse to homes) vs. open delivery network (i.e., delivery to any location);	Yes	Potential Size and Growth of the Air Cargo Market; Market Characteristics and Viability
Competition for UAS transportation or services (e.g. cargo hauling by road transportation, traditional air cargo modes etc.), providing	Yes	Competition for AAM Cargo Services

Research Question	Discussed In Economic Assessment	Section Where Question is Addressed
cost comparisons where applicable;		
Ground infrastructure requirements, legal and management strategies consistent with the envisioned UAS network for air cargo and connectivity to other transportation modalities as needed for efficient, "door-to-door" supplies, "door-to-cargo hubs", and planned or unplanned landing sites	Yes	Air cargo is a key enabler of global trade and an essential mode of transport for high-value commodities. Though air cargo is responsible for transporting less than one percent of global trade by volume, its share accounts for 35 percent of global trade by value (IATA, 2017). This equates to transporting approximately 657 million packages worth $17.8 billion are transported in a single day, or $6 trillion worth of goods annually (IATA, 2017). As demand continues to grow, it is anticipated that advanced air cargo will fulfill an increasing share of cargo transport over time. Though the advanced air cargo market is currently in its nascent stages, the next stage of industry development is expected to occur from 2022-2025 (Kovalev et al., 2019). During this stage, the US and the world will begin to see large-scale applications of UAS for commercial purposes and the expansion of their functionality. Thereafter, unmanned cargo transport is projected to gradually become more and more mainstream (Kovalev et al., 2019). Despite the optimistic signals for air cargo growth, the industry is highly competitive. As businesses determine their methods for transporting goods, cost and delivery speed are often the dominant factors (Kloss & Riedel, 2021). As such, competition for AAC services, is highly dependent on the transport mechanics of each of the four air cargo market segments: HLR, HMR, Regional, and Light. HLR and HMR aircraft are generally used to transport either high-cost or time-sensitive goods overseas or from coast to coast. The primary competition for these use cases comes from ocean freight, trucking, and intermodal shipping. Regional aircraft are anticipated to continue servicing feeder markets, while light could potentially serve where VTOL infrastructure emerges. Both regional and light aircraft use cases will compete with trucking. A summary of air cargo market segments and their primary competitors is shown in Table 6. Table 6. Air Cargo Market Segments and Their Primary Competitors. **Heavy / Long Range (HLR) | Market and Competition**

<table>
<tr><th>Research Question</th><th>Discussed In Economic Assessment</th><th>Section Where Question is Addressed</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>Mission Range: > 3,000 nautical miles
Payload: > 40 tons
Speed: 400-500 knots</td><td>Primary Niche / Market
• Transoceanic Flight
• Transport imports / exports
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Sea / Ocean Freight</td></tr>
<tr><th colspan="3">Heavy / Medium Range (HMR) | Market and Competition</th></tr>
<tr><td>Mission Range: 500-3000 nautical miles
Payload: > 10 tons
Speed: 350-500 knots</td><td>Primary Niche / Market
• Domestic & Transoceanic Flight
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Trucking / Intermodal Shipping
• Sea / Ocean Freight</td></tr>
<tr><th colspan="3">Regional (Feeder) Aircraft | Market and Competition</th></tr>
<tr><td>Mission Range: 75-1,000 nautical miles
Payload: 1-10 tons
Speed: 150-300 knots</td><td>Primary Niche / Market
• Regional Flight
• Transport high-cost goods
• Transport time-sensitive goods</td><td>Primary Competitors
• Truck / Intermodal Shipping</td></tr>
<tr><th colspan="3">Light (VTOL) Aircraft | Market and Competition</th></tr>
<tr><td>Mission Range: <250 nautical miles
Payload: 50-2,000 pounds
Speed: <200 knots</td><td>Primary Niche / Market
• Local & Regional Flight
• Transport time-sensitive goods
• May be low, medium, high cost</td><td>Primary Competitors
• Trucking / Express Carriers</td></tr>
</table>

Enabling Infrastructure</td></tr>
<tr><td>Direct and indirect economic benefits of integrating large UAS in air transport and induced economic benefits of this transformation</td><td>Yes</td><td>Economic Impact of AAM Cargo</td></tr>
</table>

6.2 Market Characteristics and Viability

Air cargo services are provided to customers in a highly complex and competitive environment. Many parties are involved to ensure air cargo is shipped on time and safely from one place to another, either domestically or internationally. Parties such as freight forwarders, 3PLs, airlines, airports, ground handlers, and truckers are responsible for packing and transporting commodities to and from airports or on and off aircraft. These processes are changing rapidly, as the air cargo industry transitions with advanced air mobility.

As AAC missions evolve, they will undergo six stages of automation. These stages are anticipated to advance from the present day and could potentially reach their culmination with full automation around 2042 (Hussain and Silver, 2021). The stages of automation are discussed below as described by Crown Consulting et al. (2021):

- ***Current State.*** In its current state, air cargo is transported by aircraft that have automated climb, cruise, and descent features. Advances in automation are greatly revolutionizing pilot controls so that other features become automated as well.
- ***Automated Taxi, Takeoff, and Landing.*** A number of aircraft have undergone successful trials where they can taxi, takeoff, and land with full automation. For example, Xwing has been developing a technology stack to convert aircraft, including a widely used Cessna Grand Caravan 208B, to function autonomously (Alamalhodaei, 2021). The Grand Caravan 208B has already successfully conducted a four-hour delivery of personal protection equipment and other essentials from Concord, California, to a Navajo reservation in Winslow, Arizona (Time, 2022).
- ***Simplified Vehicle Operations.*** Different manufacturers will produce vehicles with varying levels of autonomy as defined by the functional Simplified Vehicle Operations (SVO) pilot skill categories in which the vehicle is certified to replace the operator (GAMA, 2019). Training programs are expected to be highly tailored to the specific vehicles during the early years of SVO operations. From a licensing perspective, the functional skill categories architecture would allow operators to add skill ratings until they have effectively all the skills of a pilot today if they wish. This process is similar to what is already in place for Sport Pilots, with optional Class B airspace and night flight training and licensing available.
- ***Remotely Piloted.*** User safety and public acceptance are anticipated to be primary drivers of automated flight. Toward the transition of the transition to fully automated air cargo operations, aircraft will be remotely piloted by trained experts who are on the ground.
- ***Remotely Supervised* (1:1).** Blending with the remotely piloted phase of transition, it is expected that a remote pilot will transition from navigating an aircraft remotely to supervising an aircraft as it goes through the various stages of a flight mission.
- ***Remotely Supervised (1:n).*** In the last stage of automation, one individual will supervise multiple aircraft missions.

In the US, air freight operations are highly concentrated in large hubs, which move millions of pounds of cargo annually. Approximately two percent of the nation’s public airports handle 96 percent of its air cargo (TIME, 2021), and just three airports (Memphis International, Ted Stevens Anchorage International, and Louisville Muhammed Ali International) process approximately one-third of the nation’s cargo (derived from FAA, 2020). As the air cargo industry transitions from traditional to autonomous aircraft, it’s important to understand the dynamics of the existing air cargo industry, how it will be affected by advanced air mobility, and what new market activities will emerge.

Airports that handle cargo include primary, reliever, commercial service, and general aviation airports. Within these classifications airports that handle more than 100 million pounds of air cargo annually are designated as air cargo airports and qualify for cargo entitlement.[1] Primary airports service the vast majority of air cargo (98.3 percent) and are defined as commercial service airports that have more than 10,000 passenger boardings each year (FAA, 2020d; FAA, 2021b). Reliever airports handle the second largest share of air cargo with approximately 1.2 percent of the weight by volume (FAA, 2020d). Reliever airports are designated by the FAA to relieve congestion at commercial service airports and to provide improved general aviation access to the overall community. These may be publicly or privately-owned (FAA, 2021b). Following reliever airports, commercial service airports process approximately 0.3 percent of air cargo by volume and are defined as publicly owned airports that have at least 2,500 passenger boardings each calendar year and receive scheduled passenger service (FAA, 2020d, FAA, 2021b). Finally, general aviation airports handled 0.2 percent of air cargo and are defined as public-use airports that do not have scheduled service or have less than 2,500 annual passenger boardings (FAA, 2020d, FAA, 2021b). Table 3 shows the annual amount of air cargo handled by airport designation in year 2019.

Table 3. Annual Air Cargo Handled by Airport Designation (FAA, 2020d).

Classification	Cargo Landed Weight	Market Share
Primary	178,508,387,451	98.3%
Reliever	2,262,244,082	1.2%
Commercial Service	505,334,179	0.3%
General Aviation	298,971,393	0.2%
Total	181,574,937,105	100.0%

On an annual basis, approximately 140 US airports handle more than 100 million pounds of air cargo (FAA, 2020d). With the emergence of AAM, it is anticipated that gains in efficiency and more favorable cost-structures will generate growth within the existing air cargo markets and unlock new markets that would not be feasible without AAM. More information on how AAM will impact existing and budding markets can be found within the “Potential Size and Growth of the Air Cargo Market” section of the report. This section also contains a discussion of the key characteristics that are favorable for growth within existing and developing markets including, population density, traffic patterns, logistics and hubbing, among other variables.

Content in this section has been summarized from the Market Analysis. For more information see Task 1-2, “Air Cargo Market Characteristics and Viability.”

[1] 3.5% of total Airport Improvement Plan available for grants, is divided on a pro-rata basis according to an airport’s share of total U.S. landed cargo weight. Per 49 USC § 47114(c)(2)(C), not more than 8% of the total cargo entitlements may be apportioned for any one airport (FAA, 2021b).

6.2.1 Market Segments

There are four primary market segments that will be impacted during the transition to advanced air mobility. These segments include HLR, HMR, regional (Feeder), and light flight (VTOL and Short Takeoff and Landing [STOL]) operations, which are described below and summarized in Table 4. It is anticipated that Light and Feeder aircraft will become fully automated within the next two decades, while HLR and HMR aircraft will transition into simplified vehicle operations (Crown Consulting et al. (2021)).

- ***Heavy / long range (HLR).*** The HLR air cargo use case encompasses long distance air freight movements that range over 3,000 nautical miles. Missions include transoceanic flight and cargo payloads are greater than 40 tons (80,000 pounds). Within HLR operations, containerized and palletized freight can be accommodated on upper and lower decks and aircraft typically operate at airports in major metropolitan areas (ACRP, n.d.). Typical aircraft travel speeds are between 400-500 knots. Within the next decade, it is anticipated that few HLR aircraft will be equipped with automated taxi, takeoff, landing, and SVO; while the majority of aircraft will remain in the current state with limited automation for climb, cruise, and descent (Crown Consulting et al., 2021).
- ***Heavy / medium range (HMR).*** Spanning medium range distances from 500-3,000 nautical miles, the HMR air cargo use case covers coast-to-coast domestic flights and some shorter transoceanic flights. Typical cargo payloads are between 10-40 tons (20,000 to 80,000 pounds). Within HMR operations, containerized and palletized freight can be accommodated on upper and lower decks of lighter wide-bodied freighters or on the upper deck only when being transported on narrow-bodied freighters (ACRP, n.d.). Typical aircraft travel speeds are between 350-500 knots and flight missions serve smaller metropolitan areas. Within the next decade, it is anticipated that few HMR aircraft will be equipped with automated taxi, takeoff, landing, and SVO; while the majority of aircraft will remain in the current state with limited automation for climb, cruise, and descent (Crown Consulting et al., 2021).
- ***Regional (Feeder Aircraft).*** Regional or "feeder" aircraft provide support for HLR and HMR operations by transporting cargo to and from small- and medium-sized markets to cargo hubs. These aircraft typically do not require long runways for takeoff and landing and flights range 75-1,000 nautical miles. Flight speeds range from 150-300 knots. Missions do not include trans-oceanic flight and cargo payloads are typically 1-10 tons (2,000 20,000 pounds). Regional aircraft designed for freight may have floors with embedded rollers to help slide the freight into position (ACRP, n.d.). There may also be hook locking facilities along the floor to secure the freight (ACRP, n.d.). Some aircraft have winches built-in to help lift or lower freight, which is a big help to move and position heavy loads in the cabin (ACRP, n.d.). Within the next decade, it is anticipated that aircraft will be equipped with automated taxi, takeoff, landing, and SVO and a few will be remotely piloted (Crown Consulting et al., 2021). Within the next two decades it is anticipated that the majority of feeder aircraft will be fully autonomous and remotely supervised (Crown Consulting et al. 2021).
- ***Light (VTOL Aircraft).*** The Light air cargo use case encompasses an exciting array of new VTOL aircraft and drones to deliver cargo over 50 pounds. It is anticipated that within the next decade a combination of SVO and remotely piloted operations will occur, and within

the next two decades the majority of Light aircraft will be remotely supervised (Crown Consulting et al., 2021). The Light aircraft market segment will likely benefit from advances in AAM passenger mobility ground infrastructure, as vertipads, vertiports, and AAM passenger mobility infrastructure could also potentially service light cargo aircraft as well.

Table 4. Overview of AAM Air Cargo Use Cases (Crown Consulting et al., 2021).

Heavy / Long Range (HLR) Aircraft		
Mission Range: > 3,000 nautical miles **Payload:** > 40 tons **Speed:** 400-500 knots	**Aircraft** • Airbus A310 • Airbus A330 • Boeing 767 • Douglas MD-10	• Boeing 747 • Boeing 777 • Douglas MD-11 • Natilus Domestic • Natilus International
Heavy / Medium Range (HMR) Aircraft		
Mission Range: 500-3000 nautical miles **Payload:** > 10 tons **Speed:** 350-500 knots	**Aircraft** • Bombardier CRJ200 • Bombardier Q400 (Dash 8) • Airbus A300 • Airbus A321 • Antonov An-124 • Boeing 707 • Boeing 727	• Boeing 737 • Boeing 757 • Douglas DC-8 • Douglas DC-9 • Douglas MD-83 • Ilyushin II-96 • Tupolev Tu-204
Regional (Feeder) Aircraft		
Mission Range: 75-1,000 nautical miles **Payload:** 1-10 tons **Speed:** 150-300 knots	**Aircraft** • ATR 42 • ATR 72 • Beech 1900 • Beech 99 • Bombardier Q300 (Dash 8) • Cessna Caravan • Cessna Grand Caravan EX • Cessna SkyCourier	• Cessna Turbo Stationair HD Cargo • Fairchild Metro II • Fairchild Metro III Heavy • Fokker 50 • Saab 340B • Natilus Regional • Sabrewing Rhaegal-B
Light (VTOL) Aircraft		
Mission Range: <250 nautical miles **Payload:** 50-2,000 pounds **Speed:** <200 knots	**Aircraft** • Airbus CityAirbus • Ehang 216 (logistics) • Volocopter Volocity • Volocopter VoloDrone • Bell Apt 70 • Bell Nexus (4EX) • Bell Nextus (6HX)	• Airflow Aero STOL • Elroy Air • Joby S4 • Kitty Hawk HVSD • Lilium Jet (5 seat) • Pipistrel Nuuva V300 • Vertical Aerospace VA 1X

Content in this section has been summarized from the Market Analysis. For more information see Task 1-2, "Market Segments."

6.2.2 *Costs to Enter the Market*

The demand for air freight is limited by cost, typically priced 4–5 times that of road transport and 12–16 times that of sea transport (World Bank, 2009). Air freight rates generally range from $2.50–$4.50 per kilogram, while the value of air cargo typically exceeds $4.50 per kilogram (Baltic Exchange, 2022). Commodities shipped by air thus have high values per unit or are very time-sensitive, such as documents, pharmaceuticals, fashion garments, production samples, electronics, consumer goods, and perishable agricultural and seafood products (World Bank, 2009). They also include some inputs to meet just-in-time production and emergency shipments of spare parts (World Bank, 2009).

Costs for air cargo operations can be relatively fluid, depending on changes in aircraft technology, route characteristics, structure of operations, and energy prices. When considering operational costs, usually capital and operating costs, fees, and other expenses are considered (see the blue callout box to the right).

Air Carrier Cost Categories (World Bank, 2009)

Capital Costs

- Depreciation and amortization for purchased aircraft and rentals for leased aircraft

Operating Costs

- Aircraft fuel and oil
- Routine maintenance and major overhauls for airframe and engines
- Insurance and uninsured losses
- Flight crew salaries, expenses, and training

Airport Fees

- User charges and station expenses
- Landing and parking fees
- Route facility charges

Other expenses

- Passenger services

The average operating cost of an aircraft in flight is computed by dividing the direct operating costs plus capital costs by the number of hours of aircraft operation (World Bank, 2009). The latter is computed in terms of block hours (the time from when the blocks or chocks are removed from the wheels of the aircraft prior to takeoff to when the blocks are placed on the wheels following landing) (World Bank, 2009). The average aircraft operating costs are shown in Table 5. These costs should be considered when evaluating the costs to enter the air cargo market.

Table 5: Air Carrier Average Aircraft Operating Costs and Block Hours (FAA, 2018).

Aircraft Category	Carriers Filing Schedule P-5.2			Carriers Filing Schedule P-5.1			Total Carriers		
	Average Variable Costs per Block Hour	Average Total Costs per Block Hour	Total Block Hours	Average Variable Costs per Block Hour	Average Total Costs per Block Hour	Total Block Hours	Average Variable Costs per Block Hour	Average Total Costs per Block Hour	Total Block Hours
Wide-body more than 300 seats	$9,097	$10,351	220,210	NR	NR	NR	$9,097	$10,351	220,210
Wide-body 300 seats and below	$7,227	$8,285	2,091,230	NR	NR	NR	$7,221	$8,279	2,095,069
Four-engine wide-body	$10,007	$14,162	289,242	$6,440	$8,201	14,569	$9,836	$13,876	303,811
Three-engine wide-body	$11,938	$13,556	285,182	$4,304	$5,638	22,778	$11,373	$12,971	307,960
Two-engine wide-body	$7,125	$8,581	770,899	$1,822	$6,572	2,269	$7,110	$8,575	773,168
Narrow-body more than 160 seats	$4,096	$4,733	4,197,734	$6,746	$9,634	5,463	$4,100	$4,740	4,203,197
Narrow-body 160 seats and below	$3,512	$4,045	9,281,531	$3,781	$5,352	66,795	$3,514	$4,054	9,348,326
RJ more than 60 seats	$991	$1,388	3,565,900	$9,644	$14,758	1,240	$994	$1,392	3,567,140
RJ 60 seats and below	$1,044	$1,338	1,328,393	$1,792	$3,144	1,076	$1,045	$1,340	1,329,469
Turboprop more than 60 seats	$1,241	$1,785	116,701	$8,819	$10,864	7,099	$1,675	$2,306	123,800
Turboprop 20-60 seats	NR	NR	NR	$1,848	$3,282	4,700	$1,848	$3,282	4,700
Turboprop under 20 seats (Part 23)	$44	$796	93,751	$529	$909	1,762	$53	$798	95,513
Piston engine (Part 25)	NR	NR	NR	$2,199	$2,608	11	$2,199	$2,608	11
Piston engine (Part 23)	NR	$3,889	51,686	NR	NR	NR	NR	$3,889	51,686
Total	**$3,766**	**$4,432**	**22,292,459**	**$4,473**	**$6,174**	**127,762**	**$3,770**	**$4,442**	**22,420,221**

Content in this section has been extracted from the "Costs to Enter the Market" section of the Market Analysis (Task 1-2).

6.2.3 Competition for AAM Cargo Services

Air cargo is a key enabler of global trade and an essential mode of transport for high-value commodities. Though air cargo is responsible for transporting less than one percent of global trade by volume, its share accounts for 35 percent of global trade by value (IATA, 2017). This equates to transporting approximately 657 million packages worth $17.8 billion are transported in a single day, or $6 trillion worth of goods annually (IATA, 2017).

As demand continues to grow, it is anticipated that advanced air cargo will fulfill an increasing share of cargo transport over time. Though the advanced air cargo market is currently in its nascent stages, the next stage of industry development is expected to occur from 2022-2025 (Kovalev et al., 2019). During this stage, the US and the world will begin to see large-scale applications of UAS for commercial purposes and the expansion of their functionality. Thereafter, unmanned cargo transport is projected to gradually become more and more mainstream (Kovalev et al., 2019).

Despite the optimistic signals for air cargo growth, the industry is highly competitive. As businesses determine their methods for transporting goods, cost and delivery speed are often the dominant factors (Kloss & Riedel, 2021). As such, competition for AAC services, is highly dependent on the transport mechanics of each of the four air cargo market segments: HLR, HMR, Regional, and Light. HLR and HMR aircraft are generally used to transport either high-cost or time-sensitive goods overseas or from coast to coast. The primary competition for these use cases comes from ocean freight, trucking, and intermodal shipping. Regional aircraft are anticipated to continue servicing feeder markets, while light could potentially serve where VTOL infrastructure emerges. Both regional and light aircraft use cases will compete with trucking. A summary of air cargo market segments and their primary competitors is shown in Table 6.

Table 6. Air Cargo Market Segments and Their Primary Competitors.

Heavy / Long Range (HLR) | Market and Competition		
Mission Range: > 3,000 nautical miles **Payload:** > 40 tons **Speed:** 400-500 knots	**Primary Niche / Market** • Transoceanic Flight • Transport imports / exports • Transport high-cost goods • Transport time-sensitive goods	**Primary Competitors** • Sea / Ocean Freight
Heavy / Medium Range (HMR) | Market and Competition		
Mission Range: 500-3000 nautical miles **Payload:** > 10 tons **Speed:** 350-500 knots	**Primary Niche / Market** • Domestic & Transoceanic Flight • Transport high-cost goods • Transport time-sensitive goods	**Primary Competitors** • Trucking / Intermodal Shipping • Sea / Ocean Freight
Regional (Feeder) Aircraft | Market and Competition		
Mission Range: 75-1,000 nautical miles **Payload:** 1-10 tons **Speed:** 150-300 knots	**Primary Niche / Market** • Regional Flight • Transport high-cost goods • Transport time-sensitive goods	**Primary Competitors** • Truck / Intermodal Shipping
Light (VTOL) Aircraft | Market and Competition		
Mission Range: <250 nautical miles **Payload:** 50-2,000 pounds **Speed:** <200 knots	**Primary Niche / Market** • Local & Regional Flight • Transport time-sensitive goods • May be low, medium, high cost	**Primary Competitors** • Trucking / Express Carriers

Content in this section has been extracted from the "Costs to Enter the Market" section of the Market Analysis (Task 1-2).

6.2.4 *Enabling Infrastructure*

Airport ground infrastructure and designated trade routes form the foundation for international air cargo movement. Across the globe, there are 3,200 airports with 60,000 trade lanes (IATA, 2017), with the largest flows of air cargo occurring between East Asia and the US (Mazareanu, 2021). Over the next two decades, air cargo is projected to continue growing steadily as the world's air freighter fleet is estimated to grow by 70 percent from 1,770 to 3,010 airplanes (IATA, 2017).

Since there is no current infrastructure in place for AAC operations, the ability to convert existing traditional air cargo infrastructure will create an economical way to start to supplement traditional delivery methods. It is anticipated that AAC operations and manned air cargo operations will have many similar needs for support infrastructure, so the conversion can occur without disrupting current air cargo operations (National Academies of Sciences Engineering and Medicine, 2014).

Many of the less urban to remote areas will need expansive infrastructure build-up to support UAC operations as well as a new workforce development program for training and job placement. This will act, for many communities, as a new job opportunity and new economic growth to the region. Much of this ground infrastructure support will be expanded hanger and warehousing space. As technology advances, expanded airport operations will need to include vertiports to support VTOL operations. Table 7 shows the landing infrastructure required for air cargo use cases.

Table 7. AAM Cargo Use Case and Ground Infrastructure Required.

Use Case	Infrastructure Required
Heavy Long Range (HLR)	Long Runway
Heavy Medium Range (HMR)	Long Runway
Regional (Feeder)	Short Runway
Light (STOL and VTOL)	Short Runway / Vertiport / Flat Surface

Since the completion of the Market Analysis (Task 1-2), a report from the National Renewable Energy Laboratory (2023) has been released documenting the impacts of electrified aircraft on airport electricity infrastructure and demand. The report evaluated two airports, Colorado Springs (COS) and Newport-News Williamsburg (PHF), which currently do not have electric charging infrastructure. NREL (2023) findings demonstrate that annual electricity consumption is projected to increase significantly over the course of a year (an increase of four times at COS and 1.3 times at PHF) and during periods of peak demand (an increase greater than 10 times at COS and 8 times at PHF).

These findings have direct implications for the air cargo industry. With the advancement of AAM, many aircraft within the air cargo fleet will transition to electric charging. Thus the installation of three phase-power, electric grid retrofits, and charging infrastructure will likely be required at the airports managing existing air cargo demand as well as those looking to develop new air cargo market activity enabled by AAM.

Content in this section has been updated from the "Ground Infrastructure Requirements" section of the Market Analysis (Task 1-2).

6.2.5 COVID-19 Related Impacts on Air Cargo Markets

During the global pandemic, the air cargo industry became a lifeline for society, delivering critical medical supplies and vaccines across the globe and keeping international supply chains open. For many airlines, cargo became a vital source of revenue when passenger flights were grounded. In 2020, the air cargo industry generated $129 billion, which represented approximately a third of airlines' overall revenues (IATA, 2021).

Before the pandemic, air shipping was considered "the mode of last resort, limited to perishables and high-value goods with margins that can cover the extra expense" (Kulisch, 2021). In 2019 the average price to move air cargo was about 13 to 15 times higher than ocean, but now it is only three to five times more expensive, according to the International Air Transport Association and industry experts (sourced from Kulisch, 2021).

The changes in air cargo costs relative to shipping costs result from a number of factors. Leading up to, and exacerbated by the global pandemic, the supply chains of US businesses were tested by recording breaking lows in inventory-to-sales ratios, while supplier delivery times reached all-time highs (IATA, 2021b). Altogether, these forces worked to demonstrate that supply chains have gotten notably slower since 2019 with significant disruptions in ocean freight and intermodal shipping due to a strong demand for goods, a shortage in shipping containers, and manufacturing or port disruptions related to the pandemic or diminished trade relations between the US and China (Chouinard, 2021; IATA, 2021a). Though many of these impacts may seem temporary, there's evidence that the loss in supply chain reliability during 2020 has made global companies shift or heavily consider shifting from ocean to air freight (Sporrer, 2021). According to a McKinsey & Company survey of senior supply-chain executives from across industries and geographies, 93 percent of executives intend to make their supply chains "more flexible, agile, and resilient" (McKinsey & Company, 2021).

In many ways the pandemic was a catalyst for the air cargo industry; however, that's not to say there were not setbacks. In 2020, the global pandemic reduced air cargo transport to 51.0 million tonnes, as shown in Figure 8. Moving beyond 2020, the air cargo industry has already recovered. Approximately, 65.5 million tonnes were transported in 2021, which is a 6.9 percent increase from pre-pandemic levels) (IATA, 2021a; IATA, 2022).

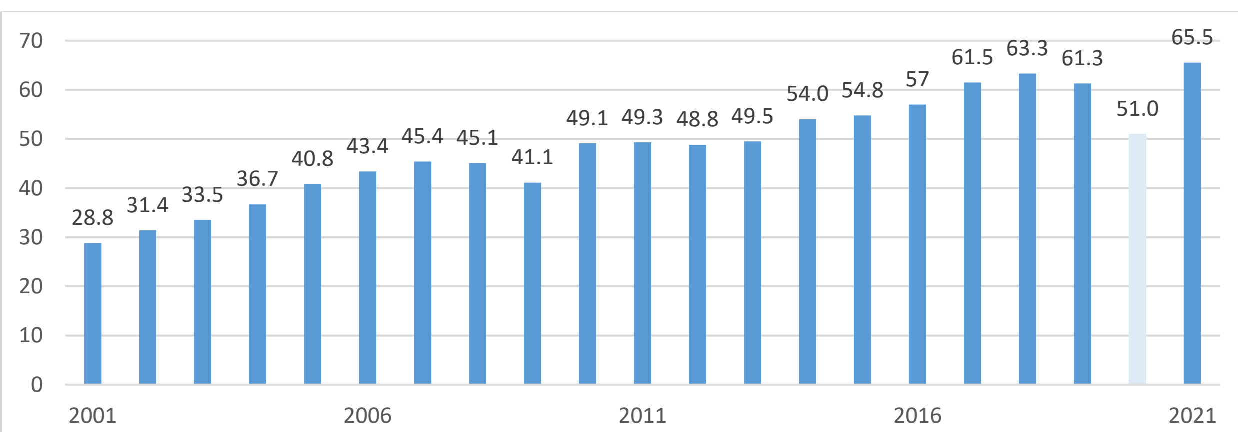


Figure 8. Millions of Freight Tonnes (IATA 2010-2022).

Since the completion of the Market Analysis (Task 1-2), more current data has become available offering additional insight on how the pandemic may impact the air cargo industry. The 2023 data shown in Figure 9 demonstrates a continuation of the trend of recovery illustrated in Figure 88. Figure 99 displays actual and seasonally Adjusted Cargo Tonne-Kilometers (ACTKs) over time, which is a measure of air freight volume transported over time. Air cargo ACTK volumes reached pre-pandemic levels in May 2023. Though difficult to ascertain a long-term trend, ACTK data may suggest that the air cargo market has weathered the effects of the COVID-19 pandemic.

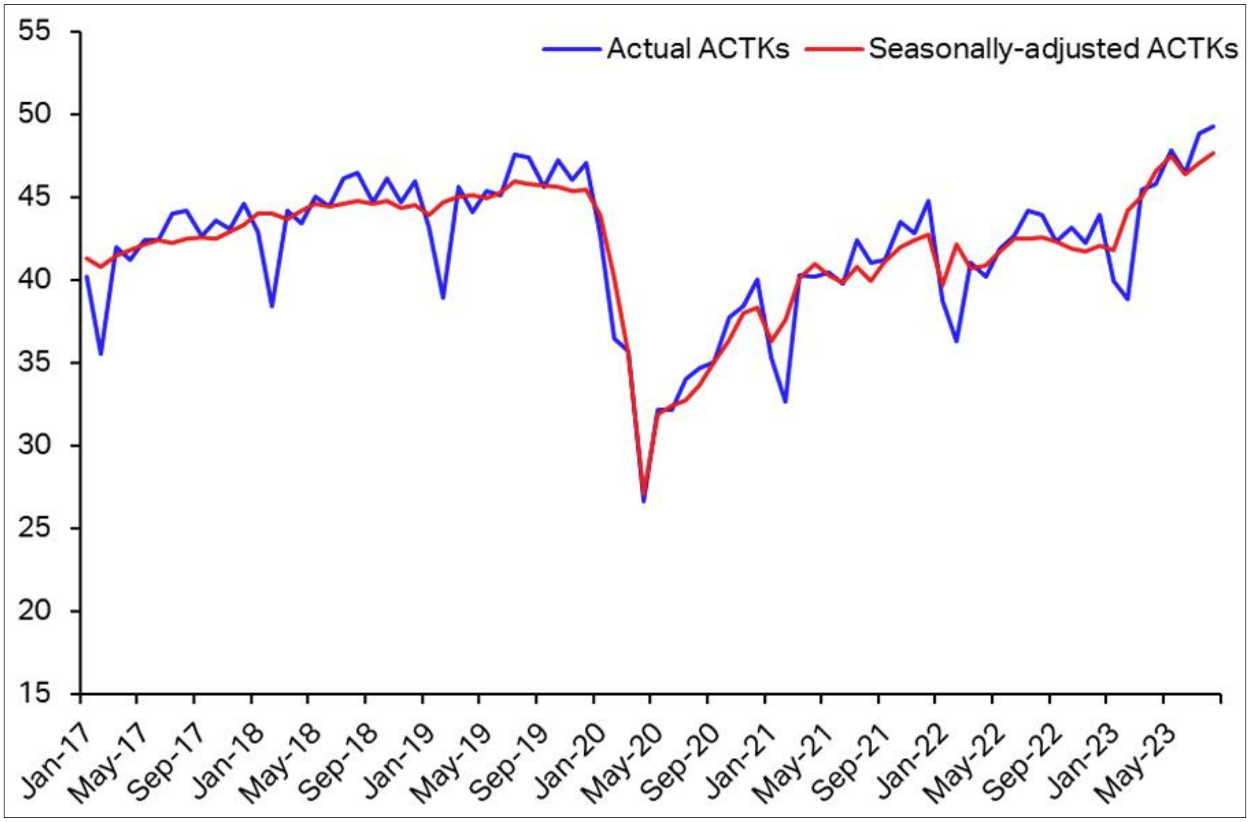


Figure 9. Actual and Seasonally Adjusted Available Cargo Tonne-Kilometers Over Time (IATA, 2023).

Content in this section has been updated from the "COVID-19 Related Impacts on AAM Cargo Markets" section of the Market Analysis (Task 1-2).

6.3 Potential Size and Growth of the Air Cargo Market

AAM air cargo is receiving a lot attention for its economic potential. According to an analysis sponsored by the Aerospace Industries Association of America (2018), large, unmanned aircraft are projected to generate $150 billion in total spending and sustain up to 60,000 jobs in research and development, manufacturing, and related services through the year 2036. Another projection from Volocopter (2021) estimates that the global market potential for logistics mobility is 100 billion euro in 2035. And an analysis from Hussain and Silver (2021) estimates that the AAM cargo mobility market will reach $58 billion by 2035 (estimate includes small package delivery). Collins (2017) discusses a future where all high-value cargo (including perishables) that is currently transported on manned aircraft could be shipped via large autonomous aircraft. AAM air cargo could potentially taking-off and land using short runways, grass runways, industrial parks, and corporate offices, while traveling distances of four to six thousand miles (Collins, 2017).

Recently, Crown Consulting et al. (2021) conducted a comprehensive market analysis of the US air cargo industry from 2020-2040. The research projected the change in market share of HLR, HMR, Feeder, and VTOL air cargo aircraft. The study accounted for low, base, and high case adoption scenarios subject to the aircraft automation levels anticipated during the 2020-2040 timeframe. The analysis used fleet turnover for HLR, HMR, and Feeder aircraft use cases, US GDP, and the price of air cargo services, as foundational elements of the analysis. Study findings demonstrated that by 2040 approximately 31 percent of the HLR fleet will be automated with SVO technology, 15 percent of the HMR fleet will be automated with SVO technology, and 78 percent of the VTOL / Feeder fleet will be remotely supervised, containing higher levels of automation (Crown Consulting et al., 2021).

Using the Crown Consulting et al. (2021) market assumptions as a foundation, a market analysis from the present-2045 was conducted to understand the growth of AAM within existing air cargo markets. This analysis was paired with Bureau of Transportation Statistics air cargo operations data to determine the key domestic markets for HLR, HMR, and Feeder air cargo transportation.

Crown Consulting et al. (2021) market assumptions were also used as the foundation to analyze the extent of AAM growth within new air cargo markets, which are projected to emerge for Feeder and Light air cargo use cases from the present-2045. In addition, a site suitability analysis was conducted to determine which locations were most suitable for new AAM Cargo markets.

Content in this section has been updated from the "Potential Size and Growth of the AAM Air Cargo Market" section of the Market Analysis (Task 1-2).

6.3.1 *AAM Growth Occurring within Existing Air Cargo Markets*

The top one percent of the United States' 5,000 airports handle more than 85 percent of its air cargo (Bureau Transportation Statistics, 2022). With the air cargo industry expecting sustained growth for the foreseeable future, it will be essential to effectively integrate AAM air cargo operations in key cargo hubs to ensure economic prosperity and growth. A map of the busiest air cargo airports is shown in Figure 1010 and a list of the top 50 busiest airports is shown in Table 9.

The US air cargo market generated an estimated $23.1 billion in 2020, comprising approximately 17.9 percent of the global market ($128.8 billion).[2] Despite some initial challenges brought about by the onset of the global pandemic (see "COVID-19 Related Impacts on Air Cargo Markets"), the US air cargo market is expected to continue to grow steadily in the near and long term, reaching an estimated $37.1 billion by 2045. Of the total $37.1 billion in air cargo revenue forecasted for year 2045, $2.3 billion in revenue will be facilitated by aircraft with SVO capabilities within the HLR and HMR use cases, $213 million by aircraft equipped with multiple levels of AAM capabilities (remotely piloted, remotely supervised [1:1], and remotely supervised [1:N]) within the Regional use case, and $107 million by STOL and VTOL aircraft within the Light use case as shown in Table 8 and /907.987.2610

Using Revenue Ton-Miles to Estimate the Size of the Air Cargo Market

When evaluating the air cargo market, a metric called revenue ton-miles is used to assess how much revenue is earned per volume of freight transported. The metric was developed to account for the revenue earned for transporting one ton of freight across one mile. In the US, the average air carrier earns $1.22 per revenue ton-mile (BTS, 2021c).

Estimates of revenue per-ton mile can be multiplied by air cargo ton-miles to derive revenue generated by air cargo operations. Air cargo revenue can then be distributed across market segments by using FAA Fleet forecasts and AAM market penetration rates developed by Crown Consulting et al. (2021).

Additional questions regarding Institutional Review Board (IRB) oversight may be directed here:

Cassie Pinkle
Research Integrity Administrator
University of Alaska Fairbanks
Contact: cjpinkel@alaska.edu11.[3,4]

Table 8. Revenue Forecasted by Air Cargo Market Segment.

Market Segment	2025	2030	2035	2040	2045
HLR + HMR share (Traditional aircraft)	$23,182,800,000	$26,477,300,000	$29,002,700,000	$31,528,200,000	$34,053,600,000
HLR + HMR share (SVO Aircraft) - Market Capture	$0	$0	$769,000,000	$1,538,000,000	$2,307,000,000

[2] Air freight ton miles (BTS, 2021b) were multiplied by the average freight revenue per ton mile (BTS, 2021c) to obtain domestic revenue.
[3] A low growth trajectory would yield $29 billion and high growth trajectory would yield $42.5 billion.
[4] Annual GDP growth is forecasted by FAA (2021a) for year 2021-2041. For this analysis, it is assumed that the same growth rate will continue from 2041 through year 2045.

Regional (Traditional aircraft)	$484,700,000	$485,200,000	$494,200,000	$460,400,000	$399,600,000
Regional (AAM Capabilities) - Market Capture	$0	$22,900,000	$37,200,000	$94,300,000	$187,100,000
Regional (AAM Capabilities) - New Markets	$0	$2,800,000	$10,300,000	$18,100,000	$25,800,000
Light (AAM Capabilities) - New Markets	$100,000	$5,200,000	$21,500,000	$64,500,000	$107,500,000

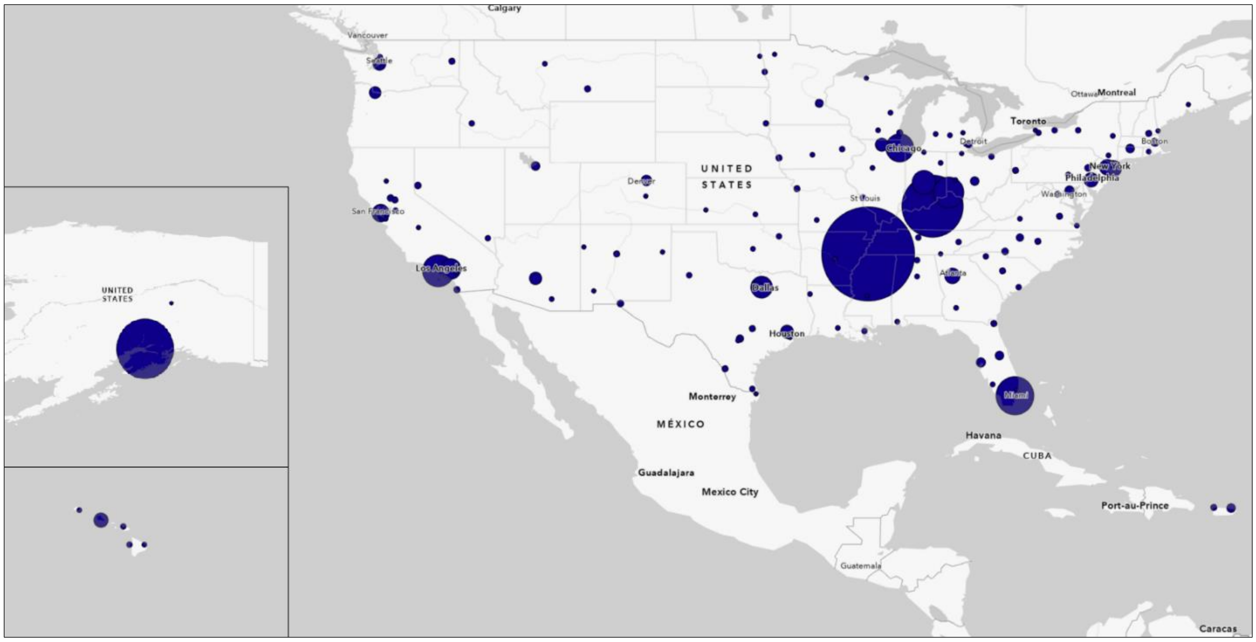


Figure 10. Cargo Airports by Landed Weight (FAA, 2020).

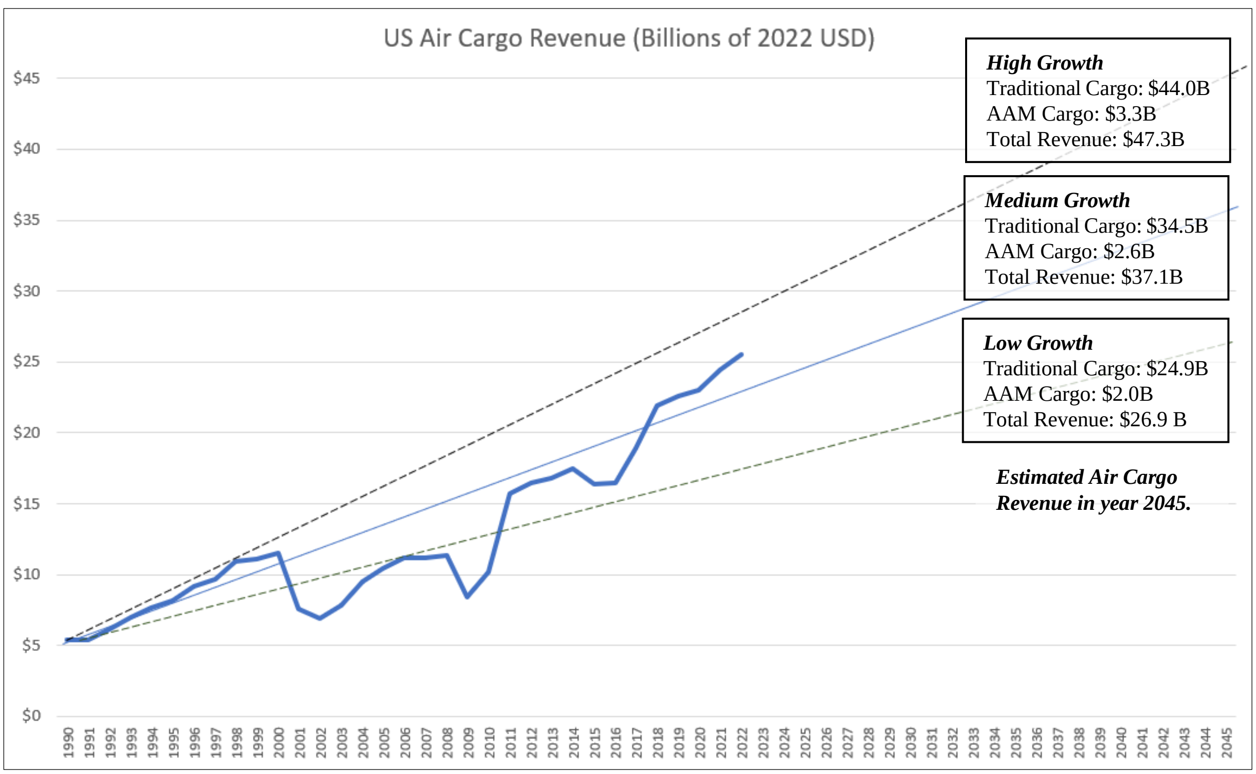


Figure 11. Economic Growth Trajectories for Air Cargo Including AAM Cargo Growth.

Table 9. Top 50 Airports by Landed Weight (in Millions of Tons; FAA 2023).

Rank	Code	City	2018	2019	2020	2021	2022	5-Year Total
1	MEM	Memphis	12.22	12.17	12.58	12.43	11.70	**61.10**
2	ANC	Anchorage	9.21	9.15	11.44	12.61	12.13	**54.54**
3	SDF	Louisville	7.32	7.80	8.38	8.75	9.08	**41.34**
4	LAX	Los Angeles	4.20	4.62	4.96	5.64	5.33	**24.76**
5	MIA	Miami	3.35	3.27	3.94	4.30	3.92	**18.77**
6	CVG	Cincinnati	3.66	3.73	6.59	7.39	5.73	**27.10**
7	ORD	Chicago	2.64	2.65	2.83	3.58	3.62	**15.31**
8	IND	Indianapolis	3.52	3.62	4.10	4.24	4.62	**20.10**
9	ONT	Ontario	2.15	2.37	2.26	1.96	2.13	**10.87**
10	DFW	Fort Worth	1.64	1.59	1.72	2.51	2.23	**9.68**
11	JFK	New York	1.81	1.84	1.84	1.95	1.86	**9.30**
12	OAK	Oakland	2.10	2.25	2.61	2.67	2.60	**12.23**
13	ATL	Atlanta	1.45	1.53	1.49	1.57	1.51	**7.56**
14	HNL	Honolulu	1.50	1.55	1.58	1.83	1.68	**8.14**
15	EWR	Newark	1.37	1.41	1.72	1.67	1.61	**7.79**
16	PHL	Philadelphia	1.23	1.41	1.57	1.62	1.63	**7.46**
17	RFD	Rockford	1.23	1.24	1.36	1.46	1.37	**6.66**
18	SEA	Seattle	1.10	1.20	1.23	1.13	1.13	**5.79**
19	IAH	Houston	0.96	1.11	1.21	1.21	1.13	**5.62**
20	PHX	Phoenix	0.75	0.82	0.91	0.92	0.90	**4.30**
21	PDX	Portland	0.84	1.01	1.07	1.19	1.19	**5.31**
22	DEN	Denver	0.54	0.51	0.62	0.66	0.58	**2.91**
23	AFW	Fort Worth	1.07	1.19	1.37	1.71	1.71	**7.04**
24	SJU	San Juan	0.60	0.60	0.67	0.67	0.63	**3.17**
25	BWI	Glen Burnie	0.63	0.61	0.74	0.83	0.85	**3.66**
26	TPA	Tampa	0.54	0.56	0.55	0.57	0.57	**2.79**
27	SLC	Salt Lake City	0.50	0.51	0.60	0.64	0.58	**2.84**
28	MCO	Orlando	0.53	0.64	0.65	0.69	0.62	**3.13**
29	LCK	Columbus	0.46	0.51	0.83	1.21	1.26	**4.27**
30	BDL	Windsor Locks	0.62	0.62	0.59	0.73	0.51	**3.06**
31	SFO	San Francisco	0.48	0.63	0.61	0.61	0.63	**2.96**
32	BOS	Boston	0.37	0.38	0.36	0.35	0.32	**1.77**
33	MSP	Minneapolis	0.46	0.48	0.47	0.45	0.46	**2.31**
34	SAT	San Antonio	0.62	0.69	0.76	0.76	0.73	**3.56**
35	GSO	Greensboro	0.42	0.45	0.44	0.47	0.44	**2.23**
36	DTW	Detroit	0.64	0.67	0.70	0.66	0.66	**3.34**
37	CLT	Charlotte	0.30	0.31	0.34	0.35	0.32	**1.62**
38	ELP	El Paso	0.34	0.47	0.38	0.58	0.53	**2.30**
39	BFI	Seattle	0.24	0.27	0.18	0.21	0.19	**1.09**
40	SAN	San Diego	0.28	0.27	0.30	0.30	0.29	**1.45**
41	MCI	Kansas City	0.35	0.32	0.36	0.38	0.39	**1.79**
42	AUS	Austin	0.28	0.29	0.30	0.35	0.37	**1.59**
43	RDU	Raleigh	0.31	0.30	0.30	0.30	0.28	**1.50**
44	RNO	Reno	0.32	0.39	0.39	0.39	0.41	**1.90**
45	MKE	Milwaukee	0.27	0.27	0.30	0.34	0.40	**1.58**
46	ABQ	Albuquerque	0.24	0.24	0.20	0.26	0.25	**1.18**
47	MHT	Manchester	0.27	0.28	0.30	0.31	0.29	**1.45**
48	IAD	Dulles	0.24	0.24	0.27	0.27	0.26	**1.28**
49	FLL	Fort Lauderdale	0.27	0.32	0.31	0.33	0.33	**1.56**
50	BQN	Aguadilla	0.25	0.28	0.32	0.37	0.37	**1.58**

Content in this section has been updated from the "Potential Size and Growth of the AAM Air Cargo Market" section of the Market Analysis (Task 1-2).

6.3.2 AAM Growth Unlocking New Air Cargo Markets

Inertia enabled by airport infrastructure, warehousing, logistics centers, population density, and the existing hub and spoke aviation networks will continue to attract air cargo activities to existing markets. However, the emergence of AAM technologies will also unlock new air cargo markets that were previously not feasible.

6.3.2.1 Site Suitability Analysis – Characteristics Favorable for New AAM Cargo Markets

General aviation airports are expected to play a crucial role in the transition to AAM air cargo, serving as gateways for new market activity. The existence of runway infrastructure, surface transportation connections, lower-density airspace, and available space for electric charging stations and power retrofits are cited as important infrastructure for AAM activities (McKinsey & Company 2023; NREL 2023; InterVISTAS 2021; NASA 2021). Though the AAM cargo landscape is still largely in development, AAM air cargo's comparative advantage is expected to exist within areas that are difficult or costly to reach by truck or other surface transportation. This includes areas with rugged topography and/or minimal connections to freight networks.

Unlike heavy long range or heavy medium range air cargo use cases that require large runways found within hub and spoke airport networks, light and regional air cargo use cases enlist aircraft that are smaller, more agile, and can be serviced by a greater array of landing infrastructure. For example, aircraft within the light use case require runway lengths as little as 100 to 300 feet, meaning that existing open spaces and rooftops of warehouses or large buildings could serve as potential "runway" candidates (InterVISTAS, 2023). Meanwhile, aircraft within the Regional use case are typically serviced by runway lengths of 4,800 feet or less, as shown in Table 10.

Though runway length is an important limiting factor for AAM cargo activity, there are a number of important site-selection variables that can help determine the most suitable locations for AAM cargo markets. As an integral part of this research, a site suitability analysis was conducted to gauge where AAM air cargo market development is most likely to occur in within the United States. To fully understand the most suitable locations for AAM passenger services, the research team reviewed more than 100 peer-reviewed journal articles, market reports, industry papers, and regulatory briefings. The literature review (Task 1-1) and Market Analysis (Task 1-2) led to the determination of 10 variables that affect AAM air cargo growth within new markets, as shown in Table 120.

Table 10. Regional Use Case Runway Characteristics (Adapted from Crown Consulting, 2021).

Regional Aircraft	Runway Length in Feet	Explanation
Cessna Turbo Stationair HD Cargo	1,970	**Grouping: 1,970'-3,000'** Services 33 percent of aircraft documented in the use case
Cessna Caravan	2,055	
Cessna Grand Caravan EX	2,160	
ATR 42	2,600	
Fairchild Metro II	3,000	
Beech 99	3,200	**Grouping: 3,001'-3,600'**
Beech 99	3,200	
Beech 1900	3,470	

Regional Aircraft	Runway Length in Feet	Explanation
Fairchild Metro III Heavy	3,500	Services 73 percent of aircraft documented in the use case
Bombardier Q300 (Dash 8)	3,600	
Bombardier Q300 (Dash 8)	3,600	
Cessna SkyCourier	3,660	**Grouping: 3,601'+** Services the remaining aircraft documented in the use case
Saab 340B	4,300	
ATR 72	4,315	
Saab 340B	4,800	

Table 11. Light Aircraft Ranges and Payloads (Crown Consulting, 2021).

Light Aircraft	Range	Payload	One-Way Distance
Ehang 216 (logistics)	22 miles	440 lbs	11-17 miles
Volocopter VoloDrone	25 miles	440 lbs	
Volocopter Velocity	31 miles	2 pax with luggage	
Bell Apt 70	35 miles	70 lbs	
Airbus CityAirbus	50 miles	4 pax (550 lbs)	25-75 miles
Bell Nexus (4EX)	60 miles	4 pax, 1 pilot, w/ luggage	
Vertical Aerospace VA-1X	100 miles	1 pilot and 4 pax (992 lbs)	
Kitty Hawk HVSD	100 miles	No data	
Bell Nextus (6HX)	150 miles	4 pax, 1 pilot, w/ luggage	
Joby S4	150 miles	4 pax, 1 pilot	
Lilium Jet (5-seat)	186 miles	5 people	93-150 miles
Pipistrel Nuuva V300	186 miles	1,014 lbs	
Airflow Aero STOL	250 miles	500 lbs	
Elroy Air	300 miles	300-500 lbs	

Serving as essential gateways for the transport of air cargo, airports were selected as the geographic unit of analysis to identify which budding markets would be most suitable for AAM cargo. During the transition from traditional to AAM air cargo (estimated to be the 2024-2045 time horizon), it is anticipated that airports will serve a vital role facilitating AAM air cargo market penetration. As existing air cargo markets are primarily fulfilled via hub-to-spoke aviation coinciding with ground infrastructure connections, it is anticipated that new air cargo markets will fulfill spoke-to-spoke, or spoke-to-last-mile deliveries that were not economically feasible prior to AAM capabilities.

With airports serving as the unit of analysis for the site suitability analysis, it is important that results are interpreted correctly. Ultimately site suitability analysis provides a ranking of airports based on the extent to which they would be suitable for emerging regional and light AAM air cargo markets (existing air cargo markets that are typically driven by HMR, HLR, and regional hub-and-spoke operations are not the focus of this analysis). The suitability analysis assumes that airports equipped with key enabling infrastructure could likely be used as "gateway" locations to transfer air cargo from regional aircraft to Light aircraft that would then complete the final delivery of cargo to warehouses, distribution centers, community centers, or other accessible locations within the feasible light aircraft flight ranges.

To illustrate the "gateway" concept airports within the state of Alaska are used as an example as shown in Figure 1212. Within Figure 1212, Alaskan airports are categorized within three groupings. Blue airports have runway lengths ranging from 1,970-3,000 feet, red airports have runways with 3,001-3,600 feet, and red airports have runway lengths greater than 3,600 feet. With all other factors held constant it can be reasoned that red airports are the most suitable for AAM cargo operations because they can service more than 73 percent of the aircraft within the regional use case (see Table 10 for a list of regional aircraft and their associated runway lengths requirements). This example provides a simplified illustration of how to determine market suitability.

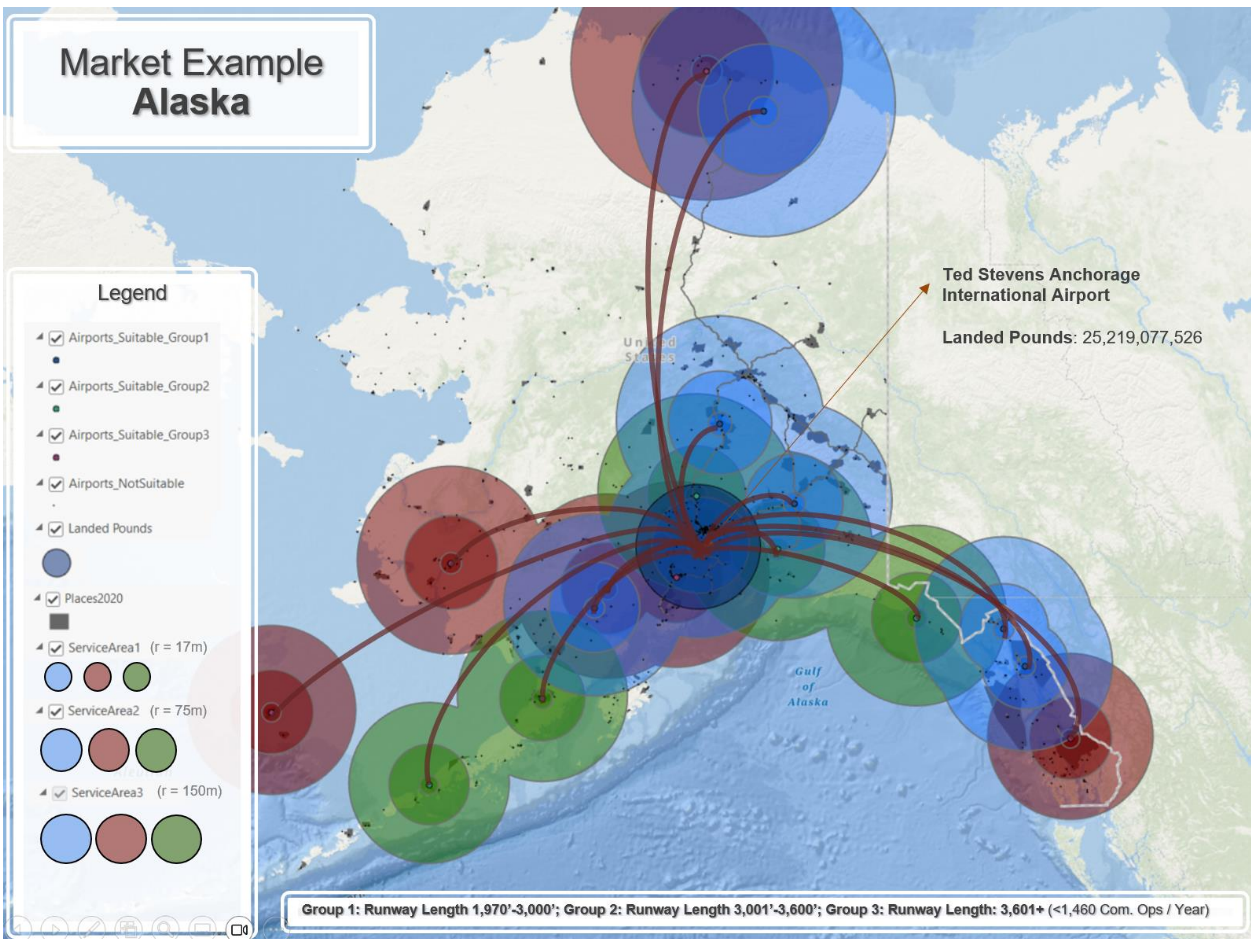


Figure 12. Site Suitability Analysis – Demonstration of AAM "Gateway" Concept.

For this research, a full site-suitability analysis was undertaken to score and rank a universe of 19,782 airports within the United States (list includes all NPIAS airports as well as other public and private airports based on their suitability for regional and light air cargo operations. After a comprehensive literature review and market analysis, 10 variables were selected. The values used within the site suitability analysis and their evaluation criteria are documented below. As an important note, a site suitability analysis workbook tool was developed to coincide with this research. The workbook tool offers default values recommended by the research team. However, the tool also allows users to adjust the weights of a site suitability variable, which in turn affects the rankings of suitable airports.

Site Suitability Analysis Evaluation Criteria

Fuel Sales. Airports have been classified into three categories based on fuel sales: those that serve Jet A fuel types, those that only serve other non-A fuel types, and those that with no access to fuel. A weight of 2 is applied to airports that sell Jet-A fuel, a weight of 1 is applied to airports that sell fuel other than Jet-A, and airports not serving fuel receive a weight of 0.

Runway Length. Airports have been classified into three categories based on runway length. Airports containing runways within the range of 1,500-3,000 feet receive a weight of 1, airports with runways within the range of 3,001 to 3,600 receive a weight of 2, and airports with runways greater than the 3,601-foot threshold receive a weight of 3.

Commercial Service Interference. Airports with annual commercial operations below the threshold value of 1,460 annual commercial operations receive full credit for this variable. Airports with annual commercial operations above the threshold value receive gradually decreasing credit based on a ratio of their commercial operations to the threshold value. (The threshold value is adjustable within the workbook tool.)

Count of Proximate Substations. Airports with as many or more substations within 10 miles as the threshold value (4 substations within 10 miles) receive full credit for this variable. Airports with fewer substations within 10 miles than the threshold value receive gradually decreasing credit based on the ratio of their substation count to the threshold value. (The threshold value is adjustable within the workbook tool.)

Proximate Population Count. Airports with equal or more population within 11 miles as the threshold value (5,000 individuals) receive full credit for this variable. Airports with less population within 11 miles than the threshold value receive gradually decreasing credit based on the ratio of their population total to the threshold value. (The threshold value is adjustable within the workbook tool.)

Freight Connections. Airports with an equal number or fewer freight connections than the threshold value (0 connections to the freight network) receive full credit for this variable. Airports with more freight connections than the threshold value receive gradually decreasing credit based on the ratio of their freight connections to the threshold value. (The threshold value is adjustable within the workbook tool.)

Terrain Ruggedness. Airports with terrain ruggedness at or above the threshold value receive full credit for this variable. Airports with terrain ruggedness below the threshold value (240m: Moderately Rugged [Extreme Appalachians, Moderate Rockies]) receive gradually decreasing credit based on the ratio of their terrain ruggedness to the threshold value. Four terrain ruggedness selections can be made within the workbook tool – 117m: Slightly Rugged (Foothills, Rolling Hills, Hill Country), 162m: Intermediately Rugged (Moderate Appalachians), 240m: Moderately Rugged (Extreme Appalachians, Moderate Rockies), 498m: Highly Rugged (Extreme Rockies).

Existing Investment. Airports can be given different values for existing investment based on the state in which they are located. Weights applied in this table reflect assumptions of the relative advantage of airports based on their state's investment. For example, a value of 1.5 assumes a 50% advantage over a value of 1.

The research team used the Simple Multi-Attribute Rating Technique (SMART) to develop suitability scores for the universe of 19,782 public and private airports in the United States. Using this approach, each airport was given a final score using the weighted average of standardized market condition attributes. Weights assigned using the SMART model reflect the relative importance of each variable to the decision-maker. The research team calibrated variable weights by emphasizing market characteristics of AAM air cargo for regional and light use cases. The final set of variables and weights is shown in Table 12.

The site suitability analysis is a first step to gauge where conditions for new AAM air cargo markets are most favorable in the US. Analysis results are shown in Table 13.

Table 12. Site Suitability Analysis Variables and Recommended Weighting.

Category	Category Description	Variable	Variable Weight	Category Weight
Enabling Infrastructure	Indicators of existing infrastructure suitable for VTOL gateways	Fuel Sales	10.0	40.0
		Runway Length	10.0	
		Commercial Service Congestion	10.0	
		Proximity of Substations	10.0	
Market Characteristics	Indicators of robust demand for specific service provided by VTOL Air Cargo	Population	10.0	40.0
		Existing Investment	10.0	
		Freight Connections	20.0	
Conditions Supporting AAM Air Cargo	Indicators of geographic factors that support air cargo development	Class G Airspace Congestion	5.0	20.0
		Class B Airspace Presence	5.0	
		Ruggedness of Service Area	10.0	

Table 13. Site Suitability Analysis Results. Top 50 Airports Suitable for AAM.

Rank	Code	Airport Name	City	State	Score
1	AFO	AFTON MUNI	AFTON	WYOMING	89.91
2	HRF	RAVALLI COUNTY	HAMILTON	MONTANA	84.93
3	BIH	BISHOP	BISHOP	CALIFORNIA	84.60
4	EBD	SOUTHERN WEST VIRGINIA RGNL	WILLIAMSON	WEST VIRGINIA	83.83
5	SBS	STEAMBOAT SPRINGS/BOB ADAMS FLD	STEAMBOAT SPRINGS	COLORADO	84.25
6	LXV	LAKE COUNTY	LEADVILLE	COLORADO	83.74
7	RIL	RIFLE GARFIELD COUNTY	RIFLE	COLORADO	83.74
8	41U	MANTI-EPHRAIM	MANTI	UTAH	83.65
9	TEX	TELLURIDE RGNL	TELLURIDE	COLORADO	83.14
10	GE99	HEAVEN'S LANDING	CLAYTON	GEORGIA	83.62
11	JFZ	TAZEWELL COUNTY	RICHLANDS	VIRGINIA	83.43
12	O46	WEED	WEED	CALIFORNIA	83.43
13	6A4	JOHNSON COUNTY	MOUNTAIN CITY	TENNESSEE	83.52
14	UKI	UKIAH MUNI	UKIAH	CALIFORNIA	83.49
15	6L4	LOGAN COUNTY	LOGAN	WEST VIRGINIA	82.35
16	RIF	RICHFIELD MUNI	RICHFIELD	UTAH	82.60
17	1A5	MACON COUNTY	FRANKLIN	NORTH CAROLINA	82.95
18	TSP	TEHACHAPI MUNI	TEHACHAPI	CALIFORNIA	83.44
19	S03	ASHLAND MUNI/SUMNER PARKER FLD	ASHLAND	OREGON	82.91
20	TRK	TRUCKEE-TAHOE	TRUCKEE	CALIFORNIA	82.54
21	PSO	STEVENS FLD	PAGOSA SPRINGS	COLORADO	83.33
22	GNB	GRANBY-GRAND COUNTY	GRANBY	COLORADO	83.32
23	RHP	WESTERN CAROLINA RGNL	ANDREWS	NORTH CAROLINA	82.13
24	2OR4	HEAVENS GATE RANCH	OAKLAND	OREGON	82.87
25	JAU	COLONEL TOMMY C STINER AIRFIELD	JACKSBORO	TENNESSEE	81.96
26	3S8	GRANTS PASS	GRANTS PASS	OREGON	82.07
27	SZT	SANDPOINT	SANDPOINT	IDAHO	83.16
28	CXP	CARSON CITY	CARSON CITY	NEVADA	81.75
29	U14	NEPHI MUNI	NEPHI	UTAH	82.46
30	MYL	MC CALL MUNI	MC CALL	IDAHO	82.71
31	7S0	RONAN	RONAN	MONTANA	82.54
32	DLS	COLUMBIA GORGE RGNL/THE DALLES MUNI	THE DALLES	OREGON	81.72
33	LGU	LOGAN-CACHE	LOGAN	UTAH	82.07
34	O22	COLUMBIA	COLUMBIA	CALIFORNIA	81.86
35	LVM	MISSION FLD	LIVINGSTON	MONTANA	81.94
36	LKP	LAKE PLACID	LAKE PLACID	NEW YORK	82.04
37	HCR	HEBER VALLEY	HEBER	UTAH	81.75
38	48I	BRAXTON COUNTY	SUTTON	WEST VIRGINIA	81.81
39	BLF	MERCER COUNTY	BLUEFIELD	WEST VIRGINIA	80.58
40	AQW	HARRIMAN-AND-WEST	NORTH ADAMS	MASSACHUSETTS	81.42
41	GOO	NEVADA COUNTY	GRASS VALLEY	CALIFORNIA	81.66
42	OMK	OMAK	OMAK	WASHINGTON	82.26
43	PVF	PLACERVILLE	PLACERVILLE	CALIFORNIA	81.53
44	LNP	LONESOME PINE	WISE	VIRGINIA	80.86
45	SPK	SPANISH FORK MUNI/WOODHOUSE FLD	SPANISH FORK	UTAH	80.91
46	PGA	PAGE MUNI	PAGE	ARIZONA	82.88
47	PBX	PIKE COUNTY/HATCHER FLD	PIKEVILLE	KENTUCKY	80.27
48	RUT	RUTLAND/SOUTHERN VERMONT RGNL	RUTLAND	VERMONT	80.91
49	BTM	BERT MOONEY	BUTTE	MONTANA	80.47
50	P52	COTTONWOOD	COTTONWOOD	ARIZONA	81.89

6.4 Economic Impact of AAM Cargo

6.4.1 Methodology & Economic Impact Terminology

The team conducted an economic impact assessment to evaluate how AAM air cargo will affect the US economy. This required defining the period of analysis (the duration of time for measuring impacts), isolating the determinants of economic impact (the key drivers that cause changes to the economy), developing the process to model economic impacts (building the economic model), and reporting the analysis findings. Please see Appendix B for additional context on the rationale, process, use cases, and aggregation used for deriving the AAM cargo growth trajectories. For this study, the period of analysis was determined to be from the present day through 2045. The team selected this period to provide a meaningful long-term economic impact estimate.

To evaluate the effect of AAM air cargo on the US economy, the research team leveraged an economic impact analysis using an input-output model. Input-output modeling is a method used in economics to analyze the interdependencies between different sectors of an economy. It provides a systematic framework for understanding how changes in one sector can affect other sectors and the overall economy. The primary concept behind input-output modeling is that each sector of the economy both consumes and produces goods and services. The input-output model represents these relationships using a matrix that shows the flows of inputs and outputs between sectors. This matrix is known as the input-output table (Munroe, 2005).

The input-output table represents the total inputs required by each sector to produce a unit of output and the total outputs produced by each sector. By examining this table, economists can analyze the direct effects of changes in demand or production in one sector as well as the indirect and induced effects on other sectors (van Leeuwen, Nijkamp, and Rietveld, 2005). The following sections provide descriptions of direct, indirect, and induced impacts.

Direct impacts - Direct economic impacts refer to the immediate effects resulting from a specific event, project, or policy change on an economy or a particular industry or sector. Typical measures for these impacts are in terms of changes in output, employment, income, or other economic indicators. Direct economic impacts are often the most easily quantifiable and readily observable effects.

Indirect impacts - Also known as secondary impacts, indirect impacts refer to the impacts that occur because of interdependencies and linkages between different sectors of the economy. Indirect impacts capture the ripple effects that arise when final demand changes in one sector leads to changes in production in other sectors to help fulfill that demand. Indirect impacts often take form as business-to-business transactions. For example, if an AAM aircraft manufacturer received a purchase order of 20 vertical takeoff and landing aircraft, that order may lead to the purchase of new parts, fabrics, software, or other factors of production sourced from other businesses. An input-output model and make table quantify these supply chain effects.

Induced impacts - Also known as tertiary impacts, induced impacts refer to the economic effects that arise from changes in household spending patterns resulting from direct and indirect impacts. Induced impacts capture the feedback loop between changes in economic activity and household consumption. These impacts reflect the effects of changes in income on consumer behavior and subsequent economic activity. An input-output model quantifies these household spending effects.

For this study, the research team used IMPLAN to conduct an economic impact analysis. IMPLAN is a platform that uses databases, economic factors, multipliers, and demographic statistics with a refined, customizable modeling system. The input-output model serves as the foundation for the economic impact analyses.

6.4.2 Air Cargo Revenue Direct Effects

By 2045, the domestic air cargo industry is projected to generate $37.1 billion in air cargo revenue, assuming a medium economic growth trajectory. Within the air cargo industry, $2.3 billion in revenue will be facilitated by aircraft with SVO capabilities within the HLR and HMR use cases, $213 million by aircraft equipped with multiple levels of AAM capabilities (remotely piloted, remotely supervised [1:1], and remotely supervised [1:N]) within the Regional use case, and $107 million by STOL and VTOL aircraft within the Light use case as shown in Table 14. From the present day through 2045, AAM market segments are projected to generate approximately $20.7 billion in cumulative revenue.

Table 14. Air Cargo Revenue by Market Segment Over Time.

Market Segment	2025	2030	2035	2040	2045
HLR + HMR share (Traditional aircraft)	$23,182,800,000	$26,477,300,000	$29,002,700,000	$31,528,200,000	$34,053,600,000
HLR + HMR share (SVO Aircraft) - Market Capture	$0	$0	$769,000,000	$1,538,000,000	$2,307,000,000
Regional (Traditional aircraft)	$484,700,000	$485,200,000	$494,200,000	$460,400,000	$399,600,000
Regional (AAM Capabilities) - Market Capture	$0	$22,900,000	$37,200,000	$94,300,000	$187,100,000
Regional (AAM Capabilities) - New Markets	$0	$2,800,000	$10,300,000	$18,100,000	$25,800,000
Light (AAM Capabilities) – New Markets	$100,000	$5,200,000	$21,500,000	$64,500,000	$107,500,000
Total Air Cargo Revenue	**$23,667,600,000**	**$26,993,400,000**	**$30,334,900,000**	**$33,703,500,000**	**$37,080,600,000**

Table 15. Cumulative AAM Air Cargo Revenue by Market Segment.

Use Case	Cumulative Revenue (2022 USD)
HLR + HMR (AAM Market Capture)	$18,455,600,000
Regional (AAM Market Capture)	$1,282,900,000
Regional (New AAM Market)	$229,500,000
Light (New AAM Market)	$767,200,000
Cumulative Air Cargo Revenue	**$20,735,300,000**

6.4.3 AAM Air Cargo Fleet Expenditure Direct Effects

By 2045 the domestic air cargo fleet is projected to grow from approximately 6,400 to 11,030 aircraft (fleet estimates are derived using FAA fleet forecasts and Crown Consulting et al. (2021) AAM cargo market penetration assumptions). Fleet growth encompasses a notable increase in AAM air cargo aircraft with 1,175 aircraft capturing existing market share (phasing out traditional HLR, HMR, and Regional aircraft) and an estimated 1,663 aircraft being used to transport cargo in new markets (see Table 16). The research estimates that from the present day through 2045, AAM aircraft capital expenditures could total $57.1 billion with approximately $44.1 billion in capital expenditures occurring in year 2045 (see Table 16, Table 17, and Table 18). Coinciding with new aircraft purchases, expenditures will be made to maintain AAM air cargo aircraft. From the present day through 2045, approximately $64.9 billion in aircraft operations and maintenance are projected, with approximately $8.2 billion in expenditures occurring in year 2045 (see Table 188 and Table 199).

Table 16. Air Cargo Fleet Over Time.

Use Case	2025	2030	2035	2040	2045
HLR + HMR share (Traditional aircraft)	4,522	5,165	5,657	6,150	6,643
HLR + HMR share (SVO Aircraft) - Market Capture	0	0	150	300	450
Regional (Traditional aircraft)	1,879	1,881	1,916	1,785	1,549
Regional (AAM Capabilities) - Market Capture	0	89	144	366	725
Regional (AAM Capabilities) - New Markets	0	11	40	70	100
Light (AAM Capabilities) - New Markets	2	75	313	938	1,563
Total Air Cargo Fleet	**6,403**	**7,221**	**8,220**	**9,608**	**11,030**

Table 17. Cumulative Air Cargo Fleet Capital Expenditures.

Use Case	2025	2030	2035	2040	2045
HLR + HMR (AAM Market Capture)	$0	$0	$16,500,000,000	$33,000,000,000	$49,500,000,000
Regional (AAM Market Capture)	$0	$593,900,000	$966,300,000	$2,449,800,000	$4,860,000,000
Regional (New AAM Market)	$0	$73,100,000	$271,000,000	$469,000,000	$667,000,000
Light (New AAM Market)	$2,600,000	$48,800,000	$406,300,000	$1,218,800,000	$2,031,300,000
Total Air Cargo Fleet CapEx	**$2,600,000**	**$715,800,000**	**$18,143,600,000**	**$37,137,600,000**	**$57,058,300,000**

Table 18. Annual Air Cargo Fleet Capital Expenditures in Year 2045.

Use Case	Annual Revenue (2022 USD)
HLR + HMR (AAM Market Capture)	$14,851,200,000
Regional (AAM Market Capture)	$15,918,000,000
Regional (New AAM Market)	$2,848,000,000
Light (New AAM Market)	$14,502,200,000
Cumulative Air Cargo Fleet CapEx	**$48,119,300,000**

Table 19. Cumulative AAM Air Cargo Fleet Operations and Maintenance Expenditures.

Use Case	2025	2030	2035	2040	2045
HLR + HMR (AAM Market Capture)	$0	$0	$7,150,300,000	$26,217,700,000	$57,202,200,000
Regional (AAM Market Capture)	$0	$226,800,000	$815,400,000	$2,027,300,000	$4,814,300,000
Regional (New AAM Market)	$0	$15,400,000	$154,000,000	$435,500,000	$860,000,000
Light (New AAM Market)	$600,000	$17,500,000	$174,700,000	$820,200,000	$2,052,600,000
Total Air Cargo Fleet OpEx	**$600,000**	**$259,700,000**	**$8,294,400,000**	**$29,500,700,000**	**$64,929,100,000**

Table 20. Annual AAM Air Cargo Fleet Operations and Maintenance Expenditures.

Use Case	Annual Revenue (2022 USD)
HLR + HMR (AAM Market Capture)	$7,150,300,000
Regional (AAM Market Capture)	$702,000,000

Regional (New AAM Market)	$96,300,000
Light (New AAM Market)	$293,400,000
Cumulative Air Cargo Fleet CapEx	**$8,242,000,000**

6.4.4 Enabling Infrastructure Expenditure Effects

Advanced air cargo will require enabling infrastructure to facilitate heavy long range, heavy medium range, regional, and light flight operations. The construction of an array of airport retrofits, electrification, and other ground infrastructure becomes increasingly necessary as AAM activities gain traction within existing markets and develop in new locations around the United States.

The construction and operation of enabling infrastructure will have a positive impact on the US economy. Projections show an estimated $187.5 million in enabling infrastructure capital expenditures being made in year 2045 with a cumulative investment of $2.2 billion across the forecast period (see Table 21 and Table 22). In alignment with new aircraft purchases, expenditures will be made to maintain enabling infrastructure. From the present day through 2045, approximately $11.9 billion in ground infrastructure operations and maintenance are projected, with approximately $1.6 billion in expenditures occurring in year 2045

Table 21. Cumulative AAM Air Cargo Enabling Infrastructure Capital Expenditures.

Use Case	2025	2030	2035	2040	2045
HLR + HMR (AAM Market Capture)	$0	$0	$116,200,000	$232,400,000	$348,500,000
Regional (AAM Market Capture)	$0	$68,700,000	$111,700,000	$283,200,000	$561,800,000
Regional (New AAM Market)	$0	$8,400,000	$31,300,000	$54,200,000	$77,100,000
Light (New AAM Market)	$1,500,000	$29,000,000	$242,000,000	$726,100,000	$1,210,200,000
AAM Air Cargo Infrastructure CapEx	**$1,500,000**	**$106,100,000**	**$501,200,000**	**$1,295,900,000**	**$2,197,600,000**

Table 22. Annual AAM Air Cargo Enabling Infrastructure Capital Expenditures.

Use Case	Annual
HLR + HMR (AAM Market Capture)	$23,200,000
Regional (AAM Market Capture)	$62,900,000
Regional (New AAM Market)	$4,600,000
Light (New AAM Market)	$96,800,000
Cumulative AAM Air Cargo Infrastructure CapEx	**$187,500,000**

Table 23. Cumulative AAM Air Cargo Enabling Infrastructure Operations & Maintenance Expenditures.

Use Case	2025	2030	2035	2040	2045
HLR + HMR (AAM Market Capture)	$0	$0	$263,400,000	$965,900,000	$2,107,500,000
Regional (AAM Market Capture)	$0	$137,200,000	$493,200,000	$1,226,300,000	$2,912,100,000
Regional (New AAM Market)	$0	$9,300,000	$93,100,000	$263,400,000	$520,200,000
Light (New AAM Market)	$1,800,000	$54,400,000	$544,700,000	$2,557,100,000	$6,398,900,000
AAM Air Cargo Infrastructure OpEx	**$1,800,000**	**$200,900,000**	**$1,394,400,000**	**$5,012,700,000**	**$11,938,700,000**

Table 24. Annual AAM Air Cargo Enabling Infrastructure Operations & Maintenance Expenditures.

Use Case	Annual
HLR + HMR (AAM Market Capture)	$
Regional (AAM Market Capture)	$
Regional (New AAM Market)	$
Light (New AAM Market)	$
Cumulative AAM Air Cargo Infrastructure OpEx	$

6.4.5 Summary of Economic Impacts – Direct, Indirect, and Induced Impacts

From 2023 to 2045, an estimated 2,838 aircraft within the domestic air cargo fleet are projected to have AAM air cargo capabilities. This will include 450 aircraft with simplified vehicle operations supporting heavy long range and heavy medium range air cargo missions within existing markets, 825 regional aircraft (725 operating within existing markets and 100 within new markets), and 1,563 light aircraft operating in new markets will come online to provide AAM air cargo services. Estimates indicate that these 2,837 aircraft will facilitate approximately $2.6 billion in AAM cargo revenue in 2045 and $20.7 billion in cumulative revenue across the forecast period.

New investments in AAM aircraft and ongoing expenditures to support their operations and maintenance will generate approximately $122.0 billion in direct output for the US economy from the present through 2045 (approximately $57.1 billion in capital expenditures and $64.9 billion in operations and maintenance expenditures). Over the same period, enabling infrastructure investments will generate approximately $14.1 billion in direct output for the US economy ($2.2 billion in capital expenditures and $12.0 billion in operations and maintenance expenditures).

Though difficult to pinpoint the precise locations where ground infrastructure investments will occur, this analysis forecasts varying levels of investment across the United States. Findings from the literature suggest AAM air cargo regional and light use cases will likely rely on airport infrastructure upgrades (McKinsey & Company 2023; NREL 2023; InterVISTAS 2021; NASA 2021) including three-phase power and electric charging capabilities for STOL and VTOL aircraft in addition to the utilization of vertiport infrastructure.

As described in "Methodology & Economic Impact Terminology", direct impacts from AAM air cargo activities generate secondary and tertiary benefits from business-to-business transactions and additional spending stemming from increases in household earnings. Altogether, the direct, indirect and induced impacts of AAM air cargo on the US economy are shown in Table 25, Table 26, Table 27, Table 28, and Table 29.

6.4.6 Workbook Tool Accompanying the Research

The research team built an excel workbook tool to explore, customize, and calculate the economic impact of AAM air cargo accompanies this research. The workbook tool enables users to estimate the economic impact of AAM air cargo by market segment across the United States. The workbook tool allows for customized economic impact analyses, in which users can adjust default values and AAM markets by entering user-provided inputs.

An online tutorial for the workbook tool can be found here: go.ncsu.edu/a42_workbook_tutorial

Table 25. Total US Jobs Supported by AAM Air Cargo Through Year 2045.

Employment		2024	2030	2035	2040	2045	Total Job Years
Air Cargo Revenue	Direct	0	175	5,195	10,630	16,290	128,460
	Indirect	0	125	3,690	7,545	11,560	91,165
	Induced	0	175	5,195	10,630	16,290	128,460
	Total	1	475	14,080	28,805	44,140	348,085
Fleet Capital Expenditures	Direct	1	505	2,895	4,855	7,450	65,670
	Indirect	3	1,260	7,235	12,135	18,620	164,175
	Induced	4	1,565	8,970	15,050	23,090	203,580
	Total	9	3,330	19,100	32,040	49,160	433,425
Fleet Operations & Maintenance	Direct	1	930	4,685	10,320	17,190	129,125
	Indirect	1	660	3,325	7,325	12,200	91,640
	Induced	1	930	4,685	10,320	17,190	129,125
	Total	3	2,520	12,695	27,965	46,580	349,890
Ground Infrastructure Capital Expenditures	Direct	5	135	840	1,060	1,180	13,845
	Indirect	3	80	505	635	710	8,305
	Induced	5	150	935	1,175	1,310	15,355
	Total	13	365	2,280	2,870	3,200	37,505
Ground Infrastructure Operations & Maintenance	Direct	3	440	2,085	5,385	9,135	65,660
	Indirect	2	265	1,250	3,230	5,480	39,395
	Induced	4	490	2,310	5,975	10,130	72,825
	Total	9	1,195	5,645	14,590	24,745	177,880
AAM Air Cargo Econ Impact	Direct	11	2,185	15,695	32,255	51,245	402,765
	Indirect	9	2,390	16,000	30,875	48,570	394,685
	Induced	15	3,310	22,095	43,150	68,010	549,345
	Total	35	7,885	53,790	106,280	167,825	1,346,795

In the year 2045, AAM air cargo will support an estimated 167,825 jobs. AAM Air Cargo will support an estimated 1.3 million job years from 2023-2045.

Table 26. Total US Employee Earnings Supported by AAM Air Cargo Through Year 2045 (2022 USD).

Labor Income		2024	2030	2035	2040	2045	Total
Air Cargo Revenue	Direct	$30,000	$13,230,000	$392,370,000	$802,800,000	$1,229,930,000	$9,699,970,000
	Indirect	$20,000	$8,570,000	$254,230,000	$520,170,000	$796,920,000	$6,285,040,000
	Induced	$20,000	$10,230,000	$303,600,000	$621,190,000	$951,690,000	$7,505,630,000
	Total	$80,000	$32,030,000	$950,200,000	$1,944,150,000	$2,978,540,000	$23,490,650,000
Fleet Capital Expenditures	Direct	$190,000	$74,420,000	$427,110,000	$716,500,000	$1,099,300,000	$9,693,000,000
	Indirect	$310,000	$121,170,000	$695,390,000	$1,166,560,000	$1,789,810,000	$15,781,570,000
	Induced	$240,000	$91,270,000	$523,790,000	$878,690,000	$1,348,140,000	$11,887,150,000
	Total	$740,000	$286,860,000	$1,646,280,000	$2,761,740,000	$4,237,250,000	$37,361,730,000
Fleet Operations & Maintenance	Direct	$90,000	$70,280,000	$353,580,000	$779,230,000	$1,297,960,000	$9,750,230,000
	Indirect	$60,000	$45,540,000	$229,100,000	$504,900,000	$841,000,000	$6,317,580,000
	Induced	$70,000	$54,380,000	$273,590,000	$602,950,000	$1,004,330,000	$7,544,510,000
	Total	$210,000	$170,200,000	$856,280,000	$1,887,090,000	$3,143,290,000	$23,612,320,000
	Direct	$480,000	$13,280,000	$82,560,000	$104,080,000	$115,950,000	$1,358,980,000

Ground Infrastructure Capital Expenditures	Indirect	$200,000	$5,640,000	$35,070,000	$44,210,000	$49,250,000	$577,240,000
	Induced	$320,000	$8,770,000	$54,530,000	$68,740,000	$76,580,000	$897,540,000
	Total	$1,000,000	$27,700,000	$172,160,000	$217,020,000	$241,790,000	$2,833,750,000
Ground Infrastructure Operations & Maintenance	Direct	$320,000	$43,310,000	$204,520,000	$528,750,000	$896,690,000	$6,444,810,000
	Indirect	$130,000	$18,400,000	$86,880,000	$224,600,000	$380,890,000	$2,737,580,000
	Induced	$210,000	$28,610,000	$135,080,000	$349,210,000	$592,210,000	$4,256,480,000
	Total	$660,000	$90,310,000	$426,470,000	$1,102,560,000	$1,869,790,000	$13,438,830,000
AAM Air Cargo Econ Impact	Direct	$1,110,000	$214,520,000	$1,460,140,000	$2,931,360,000	$4,639,830,000	$36,946,990,000
	Indirect	$720,000	$199,320,000	$1,300,670,000	$2,460,440,000	$3,857,870,000	$31,699,010,000
	Induced	$860,000	$193,260,000	$1,290,590,000	$2,520,780,000	$3,972,950,000	$32,091,310,000
	Total	$2,690,000	$607,100,000	$4,051,390,000	$7,912,560,000	$12,470,660,000	$100,737,280,000

AAM air cargo will support an estimated $12.5 billion in employee earnings in the year 2045. The industry will have supported an estimated total of $100.8 billion from 2023-2045.

Table 27. Total Gross Domestic Product Supported by AAM Air Cargo Through Year 2045 (2022 USD).

Value Added *(Gross Domestic Product)*		2024	2030	2035	2040	2045	Total
Air Cargo Revenue	**Direct**	$30,000	$14,350,000	$425,720,000	$871,030,000	$1,334,470,000	$10,524,440,000
	Indirect	$30,000	$12,300,000	$364,990,000	$746,790,000	$1,144,120,000	$9,023,250,000
	Induced	$40,000	$18,160,000	$538,740,000	$1,102,280,000	$1,688,750,000	$13,318,540,000
	Total	$110,000	$44,820,000	$1,329,450,000	$2,720,100,000	$4,167,340,000	$32,866,260,000
Fleet Capital Expenditures	**Direct**	$420,000	$161,590,000	$927,360,000	$1,555,700,000	$2,386,860,000	$21,045,990,000
	Indirect	$510,000	$197,270,000	$1,132,120,000	$1,899,200,000	$2,913,880,000	$25,692,990,000
	Induced	$420,000	$162,050,000	$930,030,000	$1,560,190,000	$2,393,750,000	$21,106,760,000
	Total	$1,340,000	$520,900,000	$2,989,500,000	$5,015,090,000	$7,694,480,000	$67,845,730,000
Fleet Operations & Maintenance	**Direct**	$100,000	$76,250,000	$383,640,000	$845,470,000	$1,408,280,000	$10,578,980,000
	Indirect	$80,000	$65,380,000	$328,910,000	$724,870,000	$1,207,400,000	$9,069,980,000
	Induced	$120,000	$96,500,000	$485,490,000	$1,069,930,000	$1,782,160,000	$13,387,520,000
	Total	$300,000	$238,130,000	$1,198,040,000	$2,640,260,000	$4,397,840,000	$33,036,470,000
Ground Infrastructure Capital Expenditures	**Direct**	$540,000	$14,900,000	$92,640,000	$116,770,000	$130,100,000	$1,524,760,000
	Indirect	$300,000	$8,350,000	$51,920,000	$65,450,000	$72,910,000	$854,540,000
	Induced	$560,000	$15,570,000	$96,760,000	$121,970,000	$135,880,000	$1,592,570,000
	Total	$1,400,000	$38,820,000	$241,310,000	$304,190,000	$338,890,000	$3,971,870,000
Ground Infrastructure Operations & Maintenance	**Direct**	$350,000	$48,590,000	$229,470,000	$593,240,000	$1,006,070,000	$7,230,940,000
	Indirect	$200,000	$27,240,000	$128,610,000	$332,490,000	$563,860,000	$4,052,650,000
	Induced	$370,000	$50,760,000	$239,680,000	$619,640,000	$1,050,840,000	$7,552,710,000
	Total	$920,000	$126,590,000	$597,760,000	$1,545,380,000	$2,620,760,000	$18,836,280,000
Air Cargo Econ Impact	**Direct**	$1,440,000	$315,680,000	$2,058,830,000	$3,982,210,000	$6,265,780,000	$50,905,110,000
	Indirect	$1,120,000	$310,540,000	$2,006,550,000	$3,768,800,000	$5,902,170,000	$48,693,410,000
	Induced	$1,510,000	$343,040,000	$2,290,700,000	$4,474,010,000	$7,051,380,000	$56,958,100,000
	Total	$4,070,000	$969,260,000	$6,356,060,000	$12,225,020,000	$19,219,310,000	$156,556,610,000

AAM air cargo will support an estimated $19.3 billion in gross domestic product (value added) in the year 2045. The industry will generate an estimated total of $156.6 billion from 2023-2045.

Table 28. Total Economic Output Supported by AAM Air Cargo Through Year 2045 (2022 USD).

Output *(Business Sales)*		2024	2030	2035	2040	2045	Total
Air Cargo Revenue	Direct	$70,000	$28,250,000	$838,110,000	$1,714,800,000	$2,627,160,000	$20,719,460,000
	Indirect	$60,000	$23,890,000	$708,730,000	$1,450,080,000	$2,221,600,000	$17,520,940,000
	Induced	$80,000	$32,400,000	$961,110,000	$1,966,460,000	$3,012,730,000	$23,760,270,000
	Total	$210,000	$84,550,000	$2,507,940,000	$5,131,340,000	$7,861,490,000	$62,000,620,000
Fleet Capital Expenditures	Direct	$1,300,000	$504,200,000	$2,893,650,000	$4,854,290,000	$7,447,780,000	$65,670,420,000
	Indirect	$1,160,000	$451,550,000	$2,591,500,000	$4,347,410,000	$6,670,080,000	$58,813,090,000
	Induced	$750,000	$289,140,000	$1,659,410,000	$2,783,760,000	$4,271,040,000	$37,659,640,000
	Total	$3,210,000	$1,244,900,000	$7,144,550,000	$11,985,460,000	$18,388,890,000	$162,143,150,000
Fleet Operations & Maintenance	Direct	$190,000	$150,120,000	$755,260,000	$1,664,470,000	$2,772,480,000	$20,826,750,000
	Indirect	$160,000	$126,940,000	$638,670,000	$1,407,520,000	$2,344,480,000	$17,611,670,000
	Induced	$220,000	$172,150,000	$866,100,000	$1,908,750,000	$3,179,370,000	$23,883,290,000
	Total	$560,000	$449,210,000	$2,260,040,000	$4,980,730,000	$8,296,320,000	$62,321,700,000
Ground Infrastructure Capital Expenditures	Direct	$890,000	$24,600,000	$152,940,000	$192,790,000	$214,790,000	$2,517,370,000
	Indirect	$550,000	$15,280,000	$94,990,000	$119,740,000	$133,410,000	$1,563,560,000
	Induced	$1,000,000	$27,770,000	$172,610,000	$217,590,000	$242,420,000	$2,841,140,000
	Total	$2,440,000	$67,650,000	$420,550,000	$530,120,000	$590,610,000	$6,922,070,000
Ground Infrastructure Operations & Maintenance	Direct	$590,000	$80,230,000	$378,860,000	$979,450,000	$1,661,030,000	$11,938,360,000
	Indirect	$360,000	$49,830,000	$235,310,000	$608,350,000	$1,031,680,000	$7,415,020,000
	Induced	$660,000	$90,550,000	$427,590,000	$1,105,440,000	$1,874,670,000	$13,473,910,000
	Total	$1,610,000	$220,610,000	$1,041,760,000	$2,693,240,000	$4,567,390,000	$32,827,330,000
AAM Air Cargo Econ Impact	Direct	$3,040,000	$787,400,000	$5,018,820,000	$9,405,800,000	$14,723,240,000	$121,672,360,000
	Indirect	$2,290,000	$667,490,000	$4,269,200,000	$7,933,100,000	$12,401,250,000	$102,924,280,000
	Induced	$2,710,000	$612,010,000	$4,086,820,000	$7,982,000,000	$12,580,230,000	$101,618,250,000
	Total	$8,030,000	$2,066,920,000	$13,374,840,000	$25,320,890,000	$39,704,700,000	$326,214,870,000

AAM air cargo will support an estimated $39.7 billion in economic output (business sales) in the year 2045. The industry will generate an estimated total of $326.2 billion from 2023-2045.

Table 29. Total Tax Revenue Generated by AAM Air Cargo Through Year 2045.

Total Tax Revenue		2024	2030	2035	2040	2045	Cumulative
Air Cargo Revenue	Direct	$8,300	$3,425,200	$101,602,800	$207,883,400	$318,488,700	$2,511,801,200
	Indirect	$7,000	$2,867,800	$85,070,300	$174,057,100	$266,665,000	$2,103,087,400
	Induced	$9,800	$4,028,700	$119,505,700	$244,513,300	$374,607,700	$2,954,391,100
	Total	$25,100	$10,321,700	$306,178,800	$626,453,800	$959,761,400	$7,569,279,300
Fleet Capital Expenditures	Direct	$59,000	$22,902,200	$131,437,200	$220,494,600	$338,297,500	$2,982,921,200
	Indirect	$97,400	$37,795,500	$216,910,400	$363,881,600	$558,291,400	$4,922,706,900
	Induced	$92,700	$35,948,800	$206,312,400	$346,102,800	$531,013,900	$4,682,189,400
	Total	$249,200	$96,646,500	$554,659,700	$930,478,500	$1,427,602,200	$12,587,811,800
Fleet Operations & Maintenance	Direct	$22,800	$18,198,800	$91,559,800	$201,782,000	$336,105,000	$2,524,809,300
	Indirect	$19,100	$15,237,500	$76,661,400	$168,948,500	$281,414,800	$2,113,978,700
	Induced	$26,800	$21,405,500	$107,693,000	$237,336,800	$395,328,100	$2,969,691,200
	Total	$68,600	$54,841,900	$275,914,200	$608,067,300	$1,012,847,800	$7,608,479,000
Ground Infrastructure Capital Expenditures	Direct	$24,400	$19,490,400	$98,057,900	$216,102,700	$359,958,800	$2,703,998,500
	Indirect	$13,200	$10,570,200	$53,179,600	$117,198,800	$195,216,100	$1,466,456,600
	Induced	$26,400	$21,067,000	$105,990,100	$233,584,000	$389,077,000	$2,922,733,300
	Total	$64,000	$51,127,700	$257,227,700	$566,885,500	$944,251,900	$7,093,188,500

Ground Infrastructure Operations & Maintenance	Direct	$76,000	$10,416,600	$49,188,300	$127,165,600	$215,656,300	$1,549,993,200
	Indirect	$41,200	$5,649,200	$26,676,200	$68,965,600	$116,956,600	$840,606,100
	Induced	$82,200	$11,259,200	$53,167,300	$137,452,400	$233,101,400	$1,675,376,800
	Total	$199,400	$27,325,000	$129,031,700	$333,583,500	$565,714,300	$4,065,976,600
AAM Air Cargo Econ Impact	Direct	$190,500	$74,433,200	$471,846,000	$973,428,300	$1,568,506,300	$12,273,523,400
	Indirect	$177,900	$72,120,200	$458,497,900	$893,051,600	$1,418,543,900	$11,446,835,700
	Induced	$237,900	$93,709,200	$592,668,500	$1,198,989,300	$1,923,128,100	$15,204,381,800
	Total	$606,300	$240,262,800	$1,523,012,100	$3,065,468,600	$4,910,177,600	$38,924,735,200

AAM air cargo will support an estimated $4.9 billion in tax revenue (local, state, and federal) in the year 2045. AAM Passenger Mobility will generate an estimated total of $38.9 billion from 2023-2045.

7 CONCLUSION

The activities conducted as a part of this project have provided information applicable to all of the research questions associated with the project, including information about the current state of air cargo, what is needed to implement UAC, the potential economic impact of UAC implementation, and where there are gaps in the technology, rules and regulations, and infrastructure required to create a functioning UAC system in the NAS.

The overarching conclusion from the interviews with the air carrier representatives is that they want to implement UAC if it is economically feasible and does not require a lot of new infrastructure, but are adopting a "wait and see" approach before implementing it to ensure that they are not wasting their time and money. Specifically, the companies have interest in the transition because they think that if UAC is financially viable, they can expand services and make more frequent deliveries that will decrease constraints on crewed aircraft (labor) and mean less spoilage or thaw (e.g., melted ice cream). However, they currently feel that the expected costs of implementing UAC are not economically feasible. In particular they believe new aircraft and infrastructure investments do not make economic sense, the performance of current technologies lags the existing fleet, the current fleet is more efficient in moving the required volume or cargo, and the UAS are not as robust as traditional aircraft and lack the ability to fly in all weather.

Other key findings from the interviews are:

- The GSE located in hubs is pretty standard and includes k-loaders, forklifts, slave pallets, belt loaders, tugs, heaters, de-ice trucks, hydraulic lifts, fuel trucks, etc. The amount of GSE needed increases as a function of the size of the operation and more rural locations have less GSE and sometimes rely on community members to help with the operations.
- The pandemic dramatically impacted cargo operations. Companies scaled up due to the increased demand and moved greater volumes of freight at the height of the pandemic in 2021 and 2022. Post pandemic, companies are experiencing pre-pandemic freight delivery levels due to time reliance on dependency, economic factors, and customers shifting demand to less critical delivery (next day delivery vs same day delivery).
- The pilot shortage is outpacing demand for provided services causing the air carriers to not be able to maintain services to certain areas due to cost.

- The companies see infrastructure and training changing to support the transition from manned aircraft to unmanned aircraft, but would like it to remain as similar as possible to current infrastructure and training requirements.
- While automated loading/unloading is great to have, currently humans are faster and more efficient inside aircraft.
- The interviewees highlighted security and safety as glaring gaps in the implementation of UAC.

Some of the key takeaways from the flight testing include the following:

- Traditional aircraft converted into remotely-piloted or autonomous aircraft flying existing cargo routes and using existing infrastructure appears to be the fastest way to enter the UAC market in rural areas with minimal costs to the air carriers.
- The pilots of the remotely-piloted aircraft believe the current set of rules and regulations is appropriate for the integration of the large, UAC aircraft into the NAS. However, they would like to have every participant in the airspace be transpondered for safety.
- The process and documentation required for obtaining permissions to operate a large drone at an airport needs clarity.
- Weather will be one of the biggest challenges in implementing year-round cargo delivery. The remote pilot in command or the autonomous system piloting the aircraft must be able to handle poor weather reporting and unexpected or unreported conditions such as high winds.
- Community engagement will be essential for the acceptance of UAS cargo deliveries in remote communities.

The economic assessment's key findings show that from 2023 to 2045, an estimated 2,838 aircraft within the domestic air cargo fleet are projected to have AAM air cargo capabilities. This will include 450 aircraft with simplified vehicle operations supporting heavy long range and heavy medium range air cargo missions within existing markets, 825 regional aircraft (725 operating within existing markets and 100 within new markets), and 1,563 light aircraft operating in new markets will come online to provide AAM air cargo services. Estimates indicate that these 2,838 aircraft will facilitate approximately $2.6 billion in AAM cargo revenue in 2045 and $20.7 billion in cumulative revenue across the forecast period.

New investments in AAM aircraft and ongoing expenditures to support their operations and maintenance will generate approximately $86.5 billion in direct output for the US economy from the present through 2045 (approximately $65.7 billion in capital expenditures and $20.8 billion in operations and maintenance expenditures). Over the same period, enabling infrastructure investments will generate approximately $14.5 billion in direct output for the US economy ($2.6 billion in capital expenditures and $12.0 billion in operations and maintenance expenditures).

Though difficult to pinpoint the precise locations where ground infrastructure investments will occur, this analysis forecasts varying levels of investment across the United States. Findings from the literature suggest AAM air cargo regional and light use cases will likely rely on airport infrastructure upgrades including three-phase power and electric charging capabilities for STOL and VTOL aircraft in addition to the utilization of vertiport infrastructure. Since there is no current infrastructure in place for advanced air cargo operations, the ability to convert existing traditional air cargo infrastructure will create an economical way to start to supplement traditional delivery methods.

Direct impacts from AAM air cargo activities generate secondary and tertiary benefits from business-to-business transactions and additional spending stemming from increases in household earnings.

Many of the less urban to remote areas will need expansive infrastructure build-up to support UAC operations as well as a new workforce development program for training and job placement. This will act, for many communities, as a new job opportunity and new economic growth to the region.

This research shows that the future for UAC is bright, but additional research, standards development, and policies and procedures are needed to bring UAC to its full potential.

8 REFERENCES

Air Cargo News (2023). Merlin completes trials for first US automated air cargo network. Online: https://www.aircargonews.net/airlines/drones/merlin-completes-trials-for-first-us-automated-air-cargo-network/

Airport Cooperative Research Program (ACRP). (No Date). Types of Aircraft Utilized for Air Cargo. Online: https://crp.trb.org/acrpwebresource1/types-of-aircraft-utilized-for-air-cargo/

businesswire. (2023b). Reliable Robotics Demonstrates the Integration of Automated Aircraft into the National Airspace System with the Federal Aviation Administration. Online: https://www.businesswire.com/news/home/20230816095903/en/Reliable-Robotics-Demonstrates-the-Integration-of-Automated-Aircraft-into-the-National-Airspace-System-with-the-Federal-Aviation-Administration

businesswire. (2023a). Reliable Robotics Flies Large Cargo Aircraft with No One On Board. Online: https://www.businesswire.com/news/home/20231206413888/en/Reliable-Robotics-Flies-Large-Cargo-Aircraft-with-No-One-On-Board

Bureau of Transportation Statistics (BTS). (2021c). Average Freight Revenue per Ton-mile.

https://www.bts.gov/content/average-freight-revenue-ton-mile

Commercial UAV News (2023). Xwing's Superpilot Becomes FAA's First 'Standard' UAS

Certification Project. Oneline: https://www.commercialuavnews.com/regulations/xwing-s-superpilot-becomes-faa-s-first-standard-uas-certification-project

Crown Consulting Inc., Georgia Tech Aerospace Systems Design Laboratory, GRA

Incorporated, LMI. (2021). NASA Automated Air Cargo Final Briefing. Increasingly

Automated Air Cargo Operations Market Survey/Study

Federal Aviation Administration . (2020b). *Urban Air Mobility and Advanced Air Mobility* .

Retrieved from faa.gov:

https://www.faa.gov/uas/advanced_operations/urban_air_mobility/

Federal Aviation Administration. (2020d). Passenger Boarding (Enplanement) and All-Cargo Data for U.S. Airports - Previous Years – Airports. Online: https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/previous_years/

Federal Aviation Administration. (2023a). Strategic Outlook for Cross-Cutting Research in Emerging Operations: UAS and AAM. Online: https://www.faa.gov/media/REDAC-04122023-FAA-UAS-Integration-Research-Update-to-REDAC-Full-Committee.

Federal Aviation Administration. (2023b). Passenger Boarding (Enplanement) and All-Cargo Data for U.S. Airports - Online: https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger

Federal Aviaion Administration. (2024). Special Airworthiness Certification. Online: https://www.faa.gov/aircraft/air_cert/airworthiness_certification/sp_awcert/experiment/sac

Hussain, A. and Silver D. (2021). Advanced Air Mobility: Can the United States Afford to Lose the Race? Deloitte Insights. Online: https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/advanced-air-mobility.html

IATA. (2023). Air Cargo Market Analysis. Online: https://www.iata.org/en/iata-repository/publications/economic-reports/air-cargo-market-analysis---august-2023/

InterVISTAS. (2021). The Future of Advanced Air Mobility (AAM) and What it Means for Airports. Online: https://www.intervistas.com/wp-content/uploads/2021/11/The-Future-of-Advanced-Air-Mobility_InterVISTAS_Nov2021-1.pdf

McKinsey & Company. (2023). Short-haul flying redefined: The promise of regional air mobility. Online: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/short-haul-flying-redefined-the-promise-of-regional-air-mobility

Medium. (2024). FAA Keeping It Cool When the Heat is On. Online: https://medium.com/faa/faa-keeping-it-cool-when-the-heat-is-on-31cf18b3de11

Merlin. (2023). Final report for FAA Contract 697DCK-22C-00261M, Development of non-system specific technology to integrate uncrewed aircraft systems (UAS) into the National Airspace System (NAS).

Munroe, D. K. (2005). Input–Output Analysis. Encyclopedia of Social Measurement. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/input-output-analysis#:~:text=Input%E2%80%93output%20(IO)%20analysis,base%20and%20input%E2%80%93output%20models.

NASA. (2021). Regional Air Mobility - Leveraging Our National Investments to Energize the American Travel Experience. Online: https://sacd.larc.nasa.gov/sacd/wp-content/uploads/sites/167/2021/04/2021-04-20-RAM.pdf

National Renewable Energy Laboratory (2023). Impacts of Regional Air Mobility and Electrified Aircraft on Airport Electricity Infrastructure and Demand. Online: https://www.nrel.gov/docs/fy23osti/84176.pdf

Time. (2021). The Best Inventions of 2021. Online: https://time.com/collection/best-inventions-2021/6115299/xwing-automated-flight-technology/

9 APPENDIX A - SURVEY

The survey and associated consent documents are contained below.

9.1.1 The Survey

To all Respondents,

Thank you very much for taking the time to help with this important study. Your input is vital for moving our country's efforts on the future of Advanced Air Mobility (AAM) [and Advanced Air Cargo (AAC) or Unmanned Air Cargo (UAC)] forward in a safe, efficient, and timely manner. We respect your time and have attempted to organize this survey in a manner which will make it easier to complete.

Further information regarding the above UAS Traffic Management (UTM) concepts/components is available at the following links:

- UTM: UTM is the traffic management paradigm incorporating small-UAS (sUAS) in particular and status/guidance is available here: https://www.faa.gov/uas/research_development/traffic_management
- AAC, AAM, UAC: The Concept of Operations (CONOPS) guiding AAM including many aspects of cargo handling (particularly UAC and Regionals) are evolving and the latest version (April, 2023) is available here: https://www.faa.gov/sites/faa.gov/files/Urban%20Air%20Mobility%20%28UAM%29%20Concept%20of%20Operations%202.0_0.pdf

The survey is broken up into 5 sections:

I. Current State of Air Cargo Operations
II. Potential for Future Air Cargo/Changes to Enable Autonomous Air Cargo
III. Current Market-Related Questions
IV. Future Market-Related Questions
V. End User-Related Questions (Exploring the Effects of Large/Medium UAC)

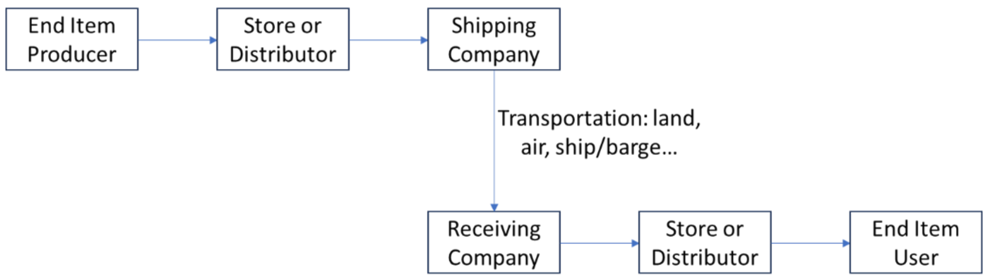
We have attempted to organize these sections to focus on the perceived interests/lines of effort of our various target audiences:

- Original Equipment Manufacturers (OEM)/Air Carriers
  - Focus on cost of aircraft, maintenance, etc
- Airport/Airfield Operations
  - Focus on infrastructure, etc
- End Users
  - Focus on premium for timely delivery, critical items, etc

Within each section, the questions are posed in 3 sets corresponding to their perceived order of importance: (1) These begin with the most critical questions for the viability of the effort (*Vital*); (2) followed by questions considered to be of moderate importance (*Significant*); (3) finally by questions of interest that would be helpful in formulating a set of well-thought strategies and recommendations (*Helpful*).

Note that while we have attempted to organize this survey in a manner which will make it more efficient and easier for all to answer, we would be most grateful for your responses to all these questions, regardless of your sector. In addition, we invite you to please include any additional information which you feel would be useful for us to record.

To help us better understand and consider the context of your inputs, we ask that you identify where in the process your organization/agency falls. We have included the following sample process flow diagram to aid in this, although we understand your position/organization may not fall exactly within any one of these categories.



Sample flow for shipment of goods.

Using the above chart, please indicate the boxes that most closely correspond to your organization/agency's function and highlight any alternate means of shipping transportation used (eg, direct from End Item Producer to End Item User). Please don't hesitate to include any information you feel is relevant to describe your organization/ agency's connection to the shipping process. However, please do not include any Personally Identifiable Information (PII) regarding yourself or organization/agency, as your response should be anonymous.

Finally, if you represent a logistics/distribution or air-carrier company/agency and are familiar with the following common types of air cargo operations, please indicate which you currently or plan to use, as this information will also be very helpful for the study:

- *HLM+HRM:* Heavy, Long-Range & Medium-Range (500 to >3000 nm) aircraft with payload capacities (10T to >40T)
- *Regional:* Regional-Range (75 – 1,000 nm) aircraft with payload capacities (1 – 10T)
- *Light:* Short-Range (<250 nm) aircraft with payload capacities (50 – 1,000 lb)

Please provide the following information about your organization:

1. Your organization/agency's function:
2. Transportation medium/technique:
3. Type(s) of air cargo operations:

Depending on your availability, we are happy to conduct this information collection in an interview format, as a stand-alone survey, or some combination thereof. Please don't hesitate to contact us with any questions, recommendations, or concerns you may have.

Again, thanks very much for your time & support!
ASSURE A42 Survey Team
Additional details on the FAA ASSURE Program are available at: https://assureuas.org/.

Section I: Current State of Air Cargo Operations

In this section, we seek to understand the current/near-term environment in which we begin to integrate requirements supporting UAC/AAC/AAM to meet the anticipated initial demand for services. Longer-term planning involving major infrastructure changes needed to support optimized UAC/AAC/AAM are addressed in Section II.

Vital

1. How many staff are typically employed at your largest operational locations?
2. How many staff are typically employed at your smallest operational locations?
3. What major Ground Support Equipment (GSE) are located at your largest operational locations (eg, hubs)? [Question (Q8) below will ask for additional details for this equipment.]
4. What major GSE are located at your smallest operational location (eg, equivalent of a "spoke" airport). [Question (Q9) below will ask for additional details on this equipment.]
5. How many ground support employees typically handle cargo aircraft offloading and onloading at your largest operational locations?
6. How many ground support employees typically handle cargo aircraft offloading and onloading at your smallest operational locations?
7. How has the pandemic affected air cargo operations (ground/flight crew number/density restrictions? Additional sanitation requirements? Increased/decreased demand? Other?)

Significant

8. Of the GSE you listed in question (Q3) above, please expand on the function each piece of equipment serves for your operation? (eg, power to the aircraft, movement of cargo, heating/cooling, pneumatic pressure for air carts, de-icing, crew access to aircraft, etc.). As your list may be quite long, please feel free to address these in decreasing order of importance to ensure we capture the most important aspects to you.
9. Of the GSE you listed in question (Q4) above, please expand on the function each piece of equipment serves for your operation? Again, as your list may still be rather long, please feel free to address these in decreasing order of importance.
10. At your largest operational locations (hubs), are all ground support employees trained and proficient on each piece of GSE? If not, please explain.
11. At your smallest operational locations (spokes), are all ground support employees trained and proficient on each piece of GSE? If not, please explain.
12. What size aircraft does your company handle? Are these HLM+HRM, Regional, or Light? (Responses in gross aircraft weight or aircraft type are appreciated).
13. Does your company primarily offer on-demand (unscheduled) or scheduled shipping services? Perhaps there is a distinction between smaller and larger facilities and service types that needs to be captured?

Helpful

14. What type of transportation network do you currently use? (eg, point to point, hub-spoke, focus-cities, etc).
15. What are the hours of operation at your largest operational locations for the applicable types above? (Please note the transportation network type listed in Q14 above.)
16. What are the hours of operation at your smallest operational locations for the applicable types above? (Please note the transportation network type listed in Q14 above.)

17. Are the locations you serve permanently staffed by company employees? By contractors? Both?
18. How long does it take to “turn” (offload and onload) (in minutes) your largest aircraft type of a fully loaded cargo aircraft? (Assume full staffing and functional GSE).
19. How long does it take to turn (in minutes) your smallest aircraft type of a fully loaded cargo aircraft? (Assume full staffing and functional GSE).
20. How does the time it takes to turn an aircraft differ between a cargo hub and a spoke location? (If applicable)
21. Who completes the required security paperwork associated with transporting cargo?
22. Who completes and delivers to the crew the required weight and balance paperwork associated with transporting cargo?
23. Who completes and delivers to the crew required NOTOC (Notice To Captain) paperwork when transporting Hazardous Materials (HAZMAT)?
24. Approximately what percentage of your cargo involves time-sensitive shipments?
25. Approximately what percentage of your business involves international shipments? How is customs handled?
26. Please offer any other comments related to the airport/cargo operations questions above.

Section II: Potential for Future Air Cargo/Changes to Enable Autonomous Air Cargo

In this section, we address any expected/potential changes to UAC/AAC/AAM to meet the anticipated demand for services. In addition to questions concerning increased/reduced staffing related to loading/unloading, we also seek to understand expectations in terms such as alternative *energy* sources (eg, electric, hydrogen) and *automation* advances required for fully autonomous operations involving staff, Communication Navigation Surveillance/information (CNS/i), or other factors. Note that while we have tried to capture relevant questions and parameters related to these factors, we invite you to provide any additional information which you feel would be helpful.

Vital

1. Do you anticipate the transition from traditional to advanced air cargo (AAC) will result in any changes in personnel or staffing (ie, increased or reduced staffing related to loading / unloading, pilots, operations or logistics centers, or any other aspects of the business)
2. Do you have any understanding of when (if) staffing changes may take place? (ie, within the next 5, 10, 15, 20 years?)
3. What are the primary changes you anticipate occurring to standard business practices due to the transition from traditional to AAC?
4. What types of new <u>aircraft</u> equipment purchases / investments are you anticipating will be made due to the transition from traditional to AAC (if any)? Do you have an estimate of the upfront (capital) and ongoing (operations and maintenance) costs associated with these purchases?
5. What types of new <u>airport infrastructure</u> investments purchases / investments are you anticipating will be made due to the transition from traditional to AAC (if any)? Do you have an estimate of the upfront (capital) and ongoing (operations and maintenance) costs associated with these purchases, or held (pending orders) which will materialize when deliveries are taken?
6. Have you had any conversations with industry players or have you read any reports that discuss any retrofits or new equipment that airports would require to accommodate Simplified Vehicle Operations (SVO) or other Advanced Air Mobility (AAM) air cargo operations (new equipment, cargo loading / unloading, instrumentation, etc)? In other words, as air cargo operations become uncrewed, are there airport infrastructure retrofits anticipated to be required? Please address whose responsibility you envision this will be to implement (eg, UAS operators, airport operators…).
7. Have you come across any resources or had any discussions with industry players about what staffing and/or operations and maintenance would look like for vertiports? (One valuable resource is the FAA's recently published Vertiport engineering guidance available here: https://www.faa.gov/airports/engineering/engineering_briefs/engineering_brief_105_vertiport_design)
8. Can loading and unloading be automated? What type of infrastructure would be required to automatically move cargo to a holding/pickup location that prevents human interaction from slowing the aviation operations? What should pickup/holding look like? Is a commercial aviation baggage claim (or a similar Concepts of Operations [CONOPS]) a workable solution?
9. Can load balancing (or at least assessment of load balancing) be automated? From both an operational and an equipment capital investment perspective, are on-board (eg, load cells in the UAS landing gear) or infrastructure (ie, scale + spatial sensing (LIDAR?) to relate center of mass to geometric centroid) solutions more attractive?

10. What interface characteristics are necessary for the UAS pilot to manage the aircraft's flight path with automated navigation?
11. How can the autonomous systems be evaluated or certified such that safe integration of UAS in the existing ATM environment or emerging UTM is enabled?
12. How will new traffic management paradigms (UTM, etc) be integrated with the currently operational NAS ATM?

Significant

13. What interface characteristics are necessary for the UAS pilot and existing and emerging businesses operators to maintain awareness of aircraft system state with automated aircraft system and subsystem control?
14. Can the UTM paradigm integrate into the large UAS environment or will a separate paradigm be required?

Helpful

15. What are the advantages and disadvantages of electric (vs traditionally fueled) vehicle operations from an infrastructure point of view (eg, ease of automation, capacity constraints, unique equipment needed, etc)? (It appears to us that electric propulsion would be a major driver in the future; and so will hydrogen-powered A/Cs when they become widely available.)
16. How many different fueling methods are required to minimally restrict the type of vehicles which can be serviced? (This could be less important for large cargo operations where fleets are serviced, as the operator mostly controls what UASs are used in the fleet).
17. How diverse are various fire-fighting infrastructure requirements?
18. Please offer any other comments related to the potential for future air cargo/changes to enable autonomous air cargo questions above. While we have attempted to capture relevant questions and parameters related to these factors, we invite you to provide any additional information which you feel would be helpful.

Section III: Current Market-Related Questions

In this section, we seek to understand how the current environment (eg, market conditions, impacts from COVID, etc) may affect your ability to conduct/support UAC/AAC/AAM operations required to meet your demand for services. As examples, we are attempting to gauge the financial impact of COVID-19 stemming from changes in ops scenarios, as well as changes in physical handling of cargo required due to COVID. We do not presume to understand all the market/environmental factors impacting your operations and we greatly appreciate any additional information you choose to provide.

Vital

1. How has the pandemic affected the air cargo market?
2. Has is changed the nature of the cargo (eg, more on-demand and less scheduled?)
3. Has the overall demand increased/decreased?
4. Is there increased demand for cargo with special handling needs?
5. What is the current greatest cost associated with your operation (eg, fuel, maintenance, personnel, etc)?
6. ?

Helpful

7. How do you expect the air cargo market to grow under the current technology?
8. Are capacity constraints projected to play a role?
9. What are primary constraints on your operation's capacity (eg, facilities, demand, financial, etc)?
10. Please offer any other comments related to the current market-related questions above.

Section IV: Future Market-Related Questions

In this section, we seek to understand how the future environment (eg, anticipated market conditions, further impacts from COVID) and potential technology development (eg, operations, vehicle capabilities, technology, automation, infrastructure, etc) may affect your ability to conduct/support anticipated UAC/AAC/AAM operations.

Significant

1. Would any of the following capabilities significantly improve your operation? Please try to be as specific as possible about any type of improvement.
    a. Operations
    b. Vehicle capabilities
    c. Technology
    d. Automation
    e. Infrastructure
    f. Other??

Helpful

2. Is there interest/funding from your company in pursuing new technologies to improve operations?
3. Please offer any other comments related to the future market-related questions above.

Section V: End User-Related Questions (Exploring the Effects of Large/Medium UAC)

In this section, we seek to understand how end-users (eg, consumers, small businesses, etc) might potentially benefit from the introduction of new UAC/AAC/AAM operations, particularly in smaller/remote communities that are currently under/marginally served by existing transportation networks and services.

Helpful

1. How often do you pay extra for faster shipping?
2. How much would you be willing to pay for even faster shipping?
3. How often does a day or 2 make a valuable difference in receiving your goods?
4. How significant would a 25% (or other number?) reduction in shipping costs be to your business/life?
5. Would a reduction in shipping cost lead to more demand for shipping from you?
6. Would a reduction in shipping time lead to more demand for shipping from you?
7. Other specific questions related to cost/time savings?
8. Would reduction in cost/training requirements associated with automated air cargo cause you to consider bringing your air cargo service in-house?
9. What is your approximate annual cost in shipping? Air-shipping?
10. Please offer any other comments/suggestions you feel might be useful for our stated goals.

9.1.2 The Survey Informed Consent Document

The purpose of this survey is to gather data for a research project sponsored by the Federal Aviation Administration (FAA) regarding perceptions and evolutionary trends relating to Advanced Air Mobility (AAM), Advanced Air Cargo (AAC), and Unmanned Air Cargo (UAC). This survey will accomplish this by addressing focus areas regarding:

1) Current State of Air Cargo Operations
2) Potential for Future Air Cargo/Changes to Enable Autonomous Air Cargo
3) Current Market-Related Questions
4) Future Market-Related Questions
5) End User-Related Questions

Intended groups targeted for this survey include (1) Original Equipment Manufacturers (OEM)/Air Carriers (focus on cost of aircraft, maintenance, etc), (2) Airport/Airfield Operations (focus on infrastructure, etc), and (3) End Users (focus on premium for timely delivery, critical items, etc).

Overall, this study will gather data relating to perceptions, attitudes, and willingness to use Advanced Air Mobility (AAM) services, specifically air cargo. Data from this survey will feed into larger ongoing research initiatives as part of a greater FAA research effort to understand how emerging trends in unmanned aviation will affect the National Airspace System (NAS).

All data gathered as part of this study will be anonymous. Thus, there are no known risks associated with this study. Generalized, aggregated data from this research will be used to generate data sets and reports regarding the current and future state of the AAM industry.

These reports and data sets will be submitted to sponsoring entities, ie, the FAA and partnering entity (ASSURE), and they may be presented at Technical Interchange Meetings (TIMs), Program Management Reviews (PMRs), conferences, and symposia. It will serve to inform the FAA regarding current and future trends in Advanced Air mobility (AAM) by identifying key public perceptions that are likely to shape the growth and development of Advanced Air Mobility (AAM) systems. Data from this study will help to reinforce other ongoing research regarding economic trends, and it will aid in informing policy and regulation with respect to a new segment of aviation.

If you have any additional questions, please contact:

Michael Hatfield, PhD, Associate Director of Education, ACUASI
University of Alaska Fairbanks (UAF)

Alaska Center for Unmanned Aircraft Systems Integration (ACUASI)
Contact: mchatfield@alaska.edu/907.987.2610

Additional questions regarding Institutional Review Board (IRB) oversight may be directed here:

Cassie Pinkle
Research Integrity Administrator
University of Alaska Fairbanks
Contact: cjpinkel@alaska.edu/907.474.7800

By clicking "I consent," you agree that the data collected from this survey may be used as described above. You may quit this survey at any time, for any reason, without penalty. If you click, "I do not consent," the survey will terminate.

Thank you!

○ I consent

○ I do not consent

10 APPENDIX B - ADDITIONAL CONTEXT ON THE RATIONALE, PROCESS, USE CASES, AND AGGREGATION USED FOR DERIVING AAM CARGO GROWTH TRAJECTORIES

Rationale. A primary component of this research was to analyze the economic impact of AAM cargo from the present day through 2045. This required developing demand forecasts for all AAM cargo operations and their associated use cases.

Process. Foundational groundwork for AAM cargo growth forecasting was established by Crown Consulting, Georgia Tech, GRA Incorporated, and LMI in their “NASA Automated Air Cargo Final Briefing” delivered on March 3, 2021. Per guidance of the project sponsor, the research team used the growth trajectory and AAM cargo market capture rates documented in this briefing as a key input for AAM cargo demand forecasting. The briefing documented AAM market capture trajectories for four use cases encompassing the domestic air cargo market, which include heavy long-range (HLR), heavy medium-range (HMR), regional (also known as feeder), and light aircraft (short takeoff and landing [STOL] and vertical takeoff and landing [VTOL] aircraft).

The NASA briefing provided AAM cargo penetration rates by use case from 2020 to 2040. Findings demonstrated that approximately 31 percent of HLR fleet growth would be captured by aircraft with simplified vehicle operations (SVO) capabilities and 69 percent of HLR fleet growth would occur with traditional aircraft over that forecast period; approximately 15 percent of HMR fleet growth would be captured by aircraft with SVO capabilities and 85 percent of the HMR fleet growth would occur with traditional aircraft; approximately 75 percent of regional aircraft would have AAM capabilities by 2040 (remotely piloted or supervised) and 25 percent of the regional fleet would still be piloted employing traditional technology; and 100 percent of light aircraft would be AAM-capable.

Findings from the NASA briefing were paired with the Bureau of Transportation Statistics Fleet data, the Federal Aviation Administration’s Aerospace Forecast, and a multitude of other guideposts to estimate the size of the air cargo fleet from the present through 2045 and the fleet’s AAM aircraft composition. Due to their similar characteristics and overlapping markets the heavy fleet (HLR and HMR) were combined for the A42 economic analysis. The economic analysis used fleet size and composition in conjunction with air cargo revenue forecasts to derive the economic impact of AAM cargo from the present through 2045. The economic impact was derived by quantifying the direct impacts of AAM cargo revenue, fleet expenditures, fleet operations and maintenance expenditures, enabling infrastructure investment, enabling infrastructure operations and maintenance expenditures, and the secondary (indirect) and tertiary (induced) impacts stemming from the direct impacts. Indirect and induced impacts were modeled using, IMPLAN, an input-output economic model. With more industry specification than RIMS-II and other industry-vetted input-output models, IMPLAN is capable of modeling the interindustry linkages of 546 industries within the U.S. economy.

As one component of the economic analysis, AAM cargo revenue growth by use case is shown in Tables 14 and 15. Table 14 shows revenue growth on an annual basis, taking a snapshot of years 2025, 2030, 2035, 2040, and 2045 and Table 15 shows cumulative revenue occurring through years 2025, 2030, 2035, 2040, and 2045. These tables show growth in both existing markets (existing trade lanes given current aircraft capabilities, their associated costs of service, and regulatory frameworks) and new markets (trade lanes that are unlocked due to new aircraft capabilities and cost structures). Based on the NASA briefing, input from the project sponsor, and information gathered from a comprehensive literature review and market analysis, it was assumed that all AAM cargo growth for the heavy use case (HLR & HMR) would occur in existing markets (market capture), that some AAM cargo growth for the regional (feeder) use case would occur in existing markets (market capture) while other regional fleet growth would occur in entirely new markets (enabled by AAM capabilities and lower associated operating costs), and that all AAM cargo growth for the light use case would occur in entirely new markets.