

An Overview of Advanced Air Mobility (AAM) Public Good Applications: Patient Transport and Organ Transport

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Advanced Air Mobility (AAM) holds the promise of “public good” applications that would support governments in providing services to citizens. This research identified a set of 59 potential applications and used a structured down-selection process to guide the choice of two for deeper analysis: Patient Transport using an Urban Air Mobility (UAM) vehicle and Organ Transport using an Unmanned Aircraft System (UAS). These applications demonstrate strong potential for federal support and integration in the United States (U.S.), particularly within the U.S. Department of Veterans Affairs (VA). The anticipated implementation timeframe is “near term” (within ~5 years), based on current regulatory, commercialization, and integration progress by AAM Original Equipment Manufacturers (OEMs). Key end users of these applications include public and private healthcare systems, Organ Procurement Organizations (OPOs), medical networks, and rural or semi-urban patient populations. Key potential benefits include reduced travel time, improved transplant outcomes, lower operating expenses compared to traditional air transport, and enhanced access to care for underserved populations. We identify implementation challenges and provide an initial cost assessment of each application. We propose avenues for future work, providing an example of aircraft sizing for the patient transport application as an example. Our recommendations include that AAM stakeholders establish pilot programs at select VA facilities, initially using existing helipads and airports, with plans to scale as technologies and regulations mature. Collaboration with AAM OEMs will be essential to identify integration requirements, including charging infrastructure, vehicle handling characteristics for both patient and organ transport, and pathways for future regulatory compliance.

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I. Nomenclature

ρ	=	atmospheric density
η_{elec}	=	electrical system efficiency
DL	=	disk loading
E	=	energy
e_{bat}	=	specific energy of battery pack
FOM	=	figure of merit
g	=	gravitational acceleration
$(L/D)_e$	=	equivalent lift-to-drag ratio
R	=	range
T	=	thrust
W_0	=	aircraft gross weight
W_{bat}	=	battery weight
W_e	=	empty weight

II. Introduction

ADVANCED Air Mobility (AAM) operations hold potential for “public good” applications that would support federal, state, local, tribal and territorial governments in the United States (U.S.) in providing services to citizens and underserved communities. This study focused on Urban Air Mobility (UAM), Regional Air Mobility (RAM), and low-altitude Unmanned Aircraft Systems (UAS) operations as candidate application categories. The U.S. federal government, state governments, and local and tribal agencies could better serve their constituents by incorporating AAM vehicles and operations to support public good applications to expand transportation. Our study aimed to further explore public good applications by building upon the foundational work presented in the 2023 NASA-sponsored report developed by Deloitte [1], and our work makes progress toward Recommendation 4.4 of the U.S.’s AAM National Strategy released in Dec 2025 [2]. We examined applications that would support federal government interests and goals with the following objectives in mind:

- Identify a set of public good applications and down-select two that have high potential to benefit from deploying AAM capabilities for more detailed analysis
- For each of the down-selected applications, define constituent missions by developing Concepts of Operations (ConOps) describing the current state and future state (with AAM) including technical and operational requirements
- Discuss key assumptions, constraints, enablers, and non-aviation systems needed
- Perform an initial cost assessment

To maintain consistency with NASA’s AAM framework, we adopted a terminology hierarchy that distinguishes between applications, missions, and use cases, as shown in Fig. 1.

1. **Application Category:** The high-level mission/domain above the specific application, implying high-level operational characteristics (e.g., *UAM, RAM*)
2. **Application:** The business application/service, providing more context and adding specificity to the application category (e.g., *Air taxi, Air ambulance, Middle-mile cargo delivery*)
3. **Mission:** overview and description of a particular application, including purpose for it and specific parameters to describe a flight
4. **Operation:** The breaking apart of the mission into operational elements, not specifying users/roles (e.g., *Vertiport departure, Vertiport arrival, On-ground energy replenishment*)
5. **Use Case:** The system’s behavior as it responds to the actions of the primary actor for the nominal (“sunny day”) operation (e.g., *Onboard PIC departs vertiport, Vertiport manager manages takeoff*)
6. **Scenario:** Specific solution path and actor(s) for contingency and off-nominal processes (e.g., *Onboard PIC departs vertiport –Contingency/Off-nominal, Vertiport manager manages takeoff –Contingency/Off-nominal*)

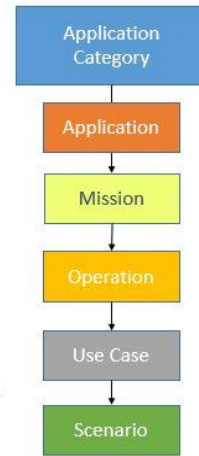


Fig. 1 Terminology hierarchy definitions.

This study focused on federally led applications, either operated directly by federal agencies or funded through federal budgets, to establish viable pathways for AAM integration into public good operations. We expect the primary benefit of AAM in public good applications to be the efficiency gained by shifting certain operations from ground-based transportation, which can experience delays that negatively impact mission objectives, to more air-based transportation. We test this theory by assessing the proposed air-based solutions, which are expected to reduce travel constraints and enable faster, more timely execution of various applications. When considering this transition of applications from a federal stakeholder perspective, this shift will enable more efficient use of resources currently consumed in ground-based operations.

Following this Introduction, Section III presents the first selected application, Patient Transport, with a description of the supporting missions; technical and operations requirements; assumptions; and an initial cost assessment. Section IV is structured similarly to Section III, while focusing on our second selected application, Organ Transport. Section V describes several avenues for possible future research, including a brief example of notional aircraft sizing for the patient transport mission. Section VI concludes the paper by summarizing our effort and providing recommendations for next steps in implementing these public good AAM applications.

We note that details of the methodology we used for choosing the applications are available in a corresponding report [3], and that report also includes additional details such as full descriptions of the 19 applications we defined beyond the 40 identified by Deloitte, non-aviation systems required to support our chosen two applications, and discussion of VA policies and procedures for patient transport.

III. Application 1: Patient Transport

A. Purpose and Scope

Our first selected application is Deloitte’s 10.8.5: Patient Transport [1]. Deloitte describes this application as transferring patients between medical facilities for better treatment or alleviating facility capacity issues. Some of the primary benefits of this application come in the form of providing a more accessible and efficient method of transportation compared to current ground and MedEvac helicopter operations [1]. In the scope of this application, accessibility is defined as increased access to medical vehicle transportation, which can be particularly limited in communities where citizens depend on neighboring cities for Emergency Medical Services (EMS) due to budget limitations in their own towns.

There are three main types of medical transportation: Non-Emergency Medical Transportation (NEMT), Urgent Care Transportation (UCT), and Emergency Care Transportation (ECT). These three types are differentiated on the severity of the patient’s medical condition and the associated time criticality of the transportation need. For NEMT, the patient’s conditions are non-life-threatening, and transportation can be performed via “normal” means (e.g., a van ride in normal road traffic). In urgent applications, the medical scenario of the patient is not imminently life-threatening but is elevated past what normal transportation means could provide to ensure best-chance recovery for the patient. ECT is needed when the patient is experiencing life-threatening conditions that require immediate medical attention, and the distinction between urgent and emergency applications is the time-to-safe arrival of the patient based on their current medical needs. [4], [5], [6]

Our focus in this application is primarily on “non-emergency” and “urgent” operations rather than “emergency” operations of medical patient transportation. Through a review of multiple federal stakeholders involved in medical response, we determined that emergency and disaster transport roles are already well-supported through existing air and ground systems [7], [8], [9] and there have been studies exploring the use of AAM emergency care transportation [10].

Although several federal agencies provide medical transportation under emergency conditions as requested by state/local authorities, the VA is distinct in its ongoing responsibility to deliver routine and urgent care to veterans across the U.S., including in remote, underserved rural communities. Unlike other agencies (e.g., Department of War (DOW)) that may maintain their own aviation assets or have streamlined contract air access (e.g., Federal Emergency Management Agency (FEMA)), the VA primarily relies on ground-based transport through a mix of in-house, volunteer, and partner-provided services. This structural reliance (coupled with increasing care demands) makes the VA a strategically important department for evaluating how AAM can close critical access gaps in non-emergency settings. We believe the VA may be able to provide an initial marketplace for AAM patient transport services that can be expanded later by the private healthcare system, which can also benefit non-veteran Americans.

B. Description of Application and its Missions

The following mission examples support the overarching application definition. We begin our analysis by defining AAM operations as they relate to urgent and non-emergency medical needs of veterans in rural communities and within VA hospital networks (Missions 1 and 2, respectively). Also included in these missions is the transportation of VA medical staff/doctors to and from facilities, patient locations, or supporting clinics in the VA Community Care Network (CCN).

Mission 1: Rural Patient Transfer (Urgent)

For matters in which a patient requires medical support, but the situation is non-life-threatening, urgent transfer of the patient is expected to use an AAM aircraft with onboard medical equipment that would support the transportation of one patient with supporting medical crew (2 – 3 medical professionals, as deemed necessary based on the level of care required) [11]. Additionally, this mission could include the transport of medical professionals to VA rural clinics and facilities that are experiencing staffing shortages. The AAM vehicle will be required to incorporate medical systems, such as oxygen tanks, medical equipment storage, High-Efficiency Particulate Air (HEPA) filtration, and enough space and locking mechanisms for a patient's gurney and/or wheelchairs. The trigger for this mission could come from a private hospital, medical facility, or doctor's office requesting a transfer of a veteran patient to a specific VA hospital, or vice versa. The need for these transports would stem from the need for specialized equipment or care that may only be provided at other facilities.

Given the state of the art of battery technology and associated range limitations of eVTOL AAM aircraft, the distance required to be covered is a key parameter for this mission. Our research identified two relevant data points:

- A U.S. General Accountability Office (GAO) study [12] found that the percentage of the veteran population living within selected distances of VA acute care facilities included 94% within 100 miles of a hospital and 99% within 100 miles of an outpatient clinic.
- A study [13] that was partly funded through the VA's Health Systems Research & Development and VA's Office of Rural Health found that, "The average one-way distance that veterans traveled to a VA primary care clinic was 44.5 miles."

Based on this data, we assumed a range of 100 miles plus the reserves specified by the FAA would be required for the rural patient transfer mission. This range assumes appropriate charging facilities are available at the hospital/clinic.

The high-level concept of operations for the current state (without AAM) starts with a helicopter assumed to be at a medical facility within controlled airspace receiving a trigger event, such as a dispatch call. Starting in Class B, C, or D airspace, it communicates with the air traffic control (ATC) tower for takeoff and to coordinate while inside of controlled airspace. At some point along the flight path, the helicopter enters uncontrolled, Class G, airspace. The helicopter is responsible for visually seeing and avoiding other air traffic. As the helicopter approaches the pick-up site, it lands in the area, not necessarily on an official helipad or airfield, and onboards the patient and medical professionals. It then conducts a return flight, deconflicting with nearby air traffic and communicating with the appropriate air traffic control facility to enter controlled airspace at the appropriate time. It then lands at the medical facility, offloads the passengers and prepares for the next trigger event. An alternative current state for Mission 1 is performance of the mission by a ground vehicle, i.e., an ambulance. In this case, the mission starts with the same trigger event, but the dispatcher decides to employ a ground vehicle rather than an aircraft. The starting and ending nodes are the same but the ground vehicle must navigate roadways and any traffic along the route.

The future state when AAM is implemented has the potential to either reduce the cost of the operation (as compared to a helicopter) or reduce the response time (as compared to an ambulance). The primary benefit mechanism for reducing cost is the anticipated lower operating costs of AAM electric aircraft (discussed in Section III.e). These aircraft might also operate from typical airports with CTOL aircraft, which would likely help reduce costs but would increase the time and complexity of operations since there would be first-/last-mile travel legs required for the patient to reach the aircraft. A secondary benefit mechanism for reducing cost is improved air traffic management integration—response time of the AAM aircraft may be reduced by automating pre-flight approvals and strategically deconflicting with other aircraft in the area. This improved air traffic management (ATM) integration may result in less operational time and a corresponding reduction in operating costs. The benefit mechanisms for reducing the response time compared to an ambulance are the more direct path ("as the crow flies"), avoiding ground traffic congestion, and faster cruising speed of the AAM aircraft. Finally, our analysis assumes that pilots are still on board the AAM aircraft; the incorporation of advanced automation/autonomy that removes onboard pilots could further reduce costs.

Mission 2: VA Hospital Patient Transfer (Urgent and Non-Emergency)

Based on the current needs seen in private hospital patient transfers between in-network locations, the second mission involves inter-hospital transfers within the VA medical network. These inter-hospital transfers would include both transferring patients and medical professionals. These operations are expected to lessen the overall expense of transfer compared to MedEvac helicopters and be more time efficient compared to current ground transportation methods. This mission uses AAM aircraft that are capable of carrying one patient with supporting medical crew (2 – 3 medical professionals, as deemed necessary based on the level of care required for the transfer), but the range is expected to be shorter than in Mission 1 based on discussions with medical professionals who mentioned the need for in-network transfers between hospitals in urban settings [9]. We assume a nominal range of 50 miles to approximate the breadth of a typical urban hospital network.

The high-level concept of operations for the current state (without AAM) is mostly similar to that for Mission 1, with the current vehicles being helicopters or ambulances. The distinction is that in Mission 2 the starting and ending nodes are both hospitals or other acute care facilities. As with Mission 1, the benefit mechanisms for the future state (with AAM) are reduced costs and response times, compared to current air and current ground operations, respectively.

C. Technical and Operational Requirements

To deepen our understanding of the application and analyze its constituent missions, we derived requirements through a literature review of current operations. Some of the more relevant requirements for the application are the distance between facilities, interior noise during transportation of the patient, ergonomics (both for the patient as well as for the medical professionals administering care), response time, and sufficient payload capacity. Noise levels within the cabin are crucial, as excessive noise from rotors, engines, or external winds can hinder the ability of medical professionals to monitor vital signs and promptly address emergent medical issues. Patient comfort and ergonomics are other important requirements, especially for patients undergoing interfacility air transport due to severe trauma, organ transplantation, high-risk surgical procedures, or acute syndromes. Additionally, payload capacity must accommodate necessary medical equipment and personnel to ensure comprehensive in-transit care. Maintaining a stable environment is essential to prevent condition deterioration.

Patient transport operations rely on specialized ground and aviation infrastructure to maintain continuity of care. For ground operations, ambulances must meet federal KKK-A-1822F safety standards while providing Americans with Disabilities Act (ADA)-compliant access and advanced medical capabilities. Similarly, air transport requires FAA-certified aircraft configured for critical care, with integrated tracking systems and biocontainment features for infectious disease cases. [14], [15], [16]

Table 1 outlines technical and operational requirements for ground and air transportation assets used during disasters or public health emergencies. Although we are not focused on such emergency applications, we use these requirements as an upper bound for the less stringent requirements for non-emergency and urgent transport operations; for our purposes, they represent “desirements.”

Table 1. Transportation Requirements for Federal Government-Provided Patient Transport During Disasters or Public Health Emergencies

Universal Accessibility <ul style="list-style-type: none">• ADA-compliant designs (56" door height, 30" wheelchair lifts)• Four-point wheelchair securement, lap/shoulder belts• Capacity for medical equipment (oxygen tanks, monitors) and service animals Vehicle Safety Standards <ul style="list-style-type: none">• KKK-A-1822F federal specifications (crashworthy construction, electrical systems)• GVS 2.0 (Ground Vehicle Standard) for rollover protection for patient compartments Medical Operations <ul style="list-style-type: none">• CAMTS-accredited medical transport capabilities• Strategic National Stockpile (SNS) compatible equipment integration	Core Patient Transport Capabilities <ul style="list-style-type: none">• Commission on Accreditation of Medical Transport Systems (CAMTS)-accredited• ADA-compliant loading/unloading systems for patients with mobility needs• Secure storage and delivery of medical oxygen and equipment• Containment protocols for infectious disease cases Aircraft & Crew Standards <ul style="list-style-type: none">• FAA 14 CFR Part 135 certified aircraft• Pilots holding First- or Second-Class FAA Medical Certificates with Instrument Meteorological Conditions (IMC) ratings and airline transport pilot (ATP) certificates• Terrain/weather avoidance systems and Night Vision Goggle (NVG)-compatible operations• Dedicated voice communication between flight and medical teams
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Communication Systems <ul style="list-style-type: none"> • P25 Phase II radios for federal/state Emergency Medical Services (EMS) coordination • Dual dispatch options (phone and app-based scheduling) Personnel & Compliance <ul style="list-style-type: none"> • State-specific vehicle/driver/insurance certifications • Minimum First Aid/CPR certification for all crew members 	Critical Care Operations <ul style="list-style-type: none"> • Appropriate personnel; a model is the military Critical Care Air Transport Team (CCATT) concept that consists of 1 physician/1 nurse/1 respiratory therapist per patient • HEPA filtration systems Infrastructure & Safety <ul style="list-style-type: none"> • Pre-approved landing zones meeting FAA AC 150/5390-2 or AC 150/5300-13 standards • Hospital helipads with 24/7 accessibility
References: [14], [15], [16], [17], [18], [19], [20], [21]	

Beyond technical and operational requirements, there are also regulatory requirements. No AAM aircraft have been certified to date by the FAA. Operations will require FAA approvals. 14 CFR Part 135, Subpart L, lists the current operational requirements for medical transportation of patients, and operations are authorized through Operations Specifications (OpSpec) for Helicopter Air Ambulance (HAA) Operations or Air Ambulance Operations – Airplane (A021 and A024, respectively), based on the type of aircraft chosen for the operations or via compliance to the associated policy under 14 CFR Part 91 [22]. Furthermore, missions under this application will occur under 14 CFR Part 135 [20]. Since the future AAM aircraft will be carrying passengers and potentially medical cargo, review of Advisory Circulars (ACs) 135-14 and 120-49 would be appropriate for the certification of Air Carriers and the associated methods and procedures required in obtaining this certification, respectively [23], [24].

D. Assumptions

Although many of the assumptions are similar for both reference missions, there are some differences. Specifically, Mission 2 will use short-range AAM aircraft capable of transporting one patient and a small medical crew. In Mission 2, the operational context is short-range transfers within a defined system, unlike Mission 1's broader geographic scope with many potential nodes in the network (not just VA facilities, but airports, private vertiports, etc.).

The assumptions outlined in Table 2 support a concept of operations in which the VA integrates AAM solutions encompassing next-generation aircraft. These mission assumptions pertain to the use of only electric vehicles for the future state of these operations.

Table 2. Assumptions for Reference Missions with All-Electric Aircraft

<i>Category</i>	<i>Mission 1: Rural Patient Transfer</i>	<i>Mission 2: VA Hospital Patient Transfer</i>
Aircraft Certification and Availability	AAM aircraft are certified and available - dedicated, shared or contracted for VA patient transport missions. Certification is assumed for MedEvac operations under 14 CFR Part 135 or operating under a public aircraft exemption.	<i>Same as Mission 1.</i>
Payload	Aircraft support 2,000-3,000 lb. payload (2 pilots ^{†††} , 1 patient + 2-3 medical crew + equipment)	<i>Same as Mission 1.</i>
Range	Up to 100 miles usable range (plus Visual Flight Rules reserves) [12], [13].	Shorter range, less than 100 miles.
First- and Last-Mile Transportation	Not always required. If patient needs additional transportation assistance to and from a medical facility or aircraft takeoff and landing location (e.g., a local airport), it can be provided via van or ground ambulance for urgent transfers or through contracted transportation network companies (e.g., Uber and Lyft) and volunteer programs like DAV for non-urgent transfers.	Not expected to be incorporated into this mission since the aircraft is expected to directly transport patients from facility to facility that have helipads/landing areas for UAM aircraft.

^{†††} A two-pilot operation is assumed here for initial operations, but AAM may enable single-pilot operations in the near term and eventually no onboard pilot over a longer time horizon.

Aircraft Dispatch Readiness	Aircraft can be rapidly deployed due to electric propulsion (minimal startup time) assuming pilots and crew are available. Other dispatch considerations will include pilot availability, aircraft energy state, and weather.	<i>Same as Mission 1.</i>
Turnaround Operations	Fast charging facilities (i.e., sufficiently fast to allow turnaround times that enable multiple daily flights) are available at both ends (e.g., power carts or fixed chargers).	<i>Same as Mission 1.</i>
Medical Configuration	Aircraft are fitted for gurney patients and emergency care (oxygen, intravenous equipment (IV), monitors, defibrillator, etc.).	<i>Same as Mission 1.</i>
Piloting Requirements	Pilots will be required to hold an instrument rating, a second-class FAA-issued medical certificate, and hold at least 2,000 flight hours, where at least 1,000 hours are as pilot-in-command. Night operations will require additional training [23].	<i>Same as Mission 1.</i>
Medical Crew Accommodation	Cabin supports 2–3 medical professionals providing care in transit as determined by the urgency and/or medical professional.	<i>Same as Mission 1.</i> Medical professional requirements differ based on the urgency
VA System Integration	Missions integrate with existing VA dispatch and care coordination (e.g., Veteran’s Transportation Service), with clinicians triggering transport requests as needed.	<i>Same as Mission 1.</i>
Landing Infrastructure	Urban VA sites use existing helipads; rural sites use flat zones, airports, or retrofits to existing infrastructure (like parking lots, rooftops etc.); VA adds vertiports over time at its facilities.	Primarily uses existing urban helipads and future vertiports as they become available; less emphasis on Short TakeOff and Landing (STOL)/CTOL options as compared to Mission 1.
Airspace Access and Management	Missions have access to low-altitude airspace while avoiding restricted zones such as Temporary Flight Restrictions (TFRs) and, if flying to/from major airports, have access to standard commercial approach/departure paths.	<i>Same as Mission 1.</i>
Weather	Missions are performed in both visual and instrument meteorological conditions. Aircraft do not operate in severe weather conditions (e.g., storms, icing), and backup transport options are assumed in these cases.	<i>Same as Mission 1.</i>
Funding	The VA covers costs through internal budgets or reimbursable arrangements with AAM providers.	<i>Same as Mission 1.</i>

E. Cost Assessment of Patient Transport

Current Costs of Ground Transport

The costs associated with providing ground-based NEMT services can be significant. Table 3 shows some generic estimates of NEMT pricing for a variety of services.

Table 3. Ground-Based Non-Emergency Medical Transportation Rates [25]

Types of Charge	Weekday Business Hours	Weekends & Off Hours	Holidays
Ambulatory – Base Rate	\$25 - \$30	\$30 - \$40	\$35 - \$45
Wheelchair – Base Rate	\$45 - \$50	\$75 - \$90	\$85 - \$100
Stretcher – Base Rate	\$100 - \$200	\$125 - \$225	\$150 - \$250
<i>Plus Time and Mileage</i>			
Mileage Fees	\$3 - \$5 Per Mile	\$5 - \$7 Per Mile	\$5 - \$10 Per Mile
Wait-Time Fees (per 30 minutes)	\$15 - \$30	\$15 - \$30	\$15 - \$30
Additional Attendant Fees (per 30 minutes)	\$5 - \$10	\$5 - \$10	\$5 - \$10

We note that these are nominal retail prices from private providers, not operating costs, and the estimates are most relevant for transportation across short distances within an urban or metropolitan area. Even so, these estimates would appear to suggest that AAM services could have a difficult time competing with short-haul ground-based services on a direct cost basis, at least initially, as will be discussed below.

On the other hand, a more relevant baseline may be either individual or shared transportation of patients over longer distances, which might be a better target for AAM services. The VA itself operates the Highly Rural Transportation Grant (HRTG) program that helps veterans in specific rural areas travel to VA or VA-authorized health care facilities. This is a small program with an annual budget of around \$3 million. The VA estimates that over one-third of enrolled veterans live in rural or highly rural areas, so there is a recognized need for transport over longer distances than just within a metropolitan area.

Although it is difficult to construct accurate estimates, using the above numbers we see that ground transport services over long distances could be quite expensive: assuming \$5 per mile plus \$250 in other costs, a one-way 100-mile trip would cost on the order of \$750. As will be suggested below, if new AAM technologies can be operated more cost-effectively than current air transportation options, they may be competitive with ground-based costs and provide significant time savings as well.

Current Costs of Air Transport

Although the above discussion suggests that AAM vehicles may be better suited to non-emergency or urgent care missions, it is still useful to assess the current baseline for how air ambulance patient transport (which includes emergency care) is accomplished today using conventional aircraft. A starting point for characterizing the current market is to identify the overall size of the aircraft-based air ambulance market and what types of aircraft are currently used. A downstream refinement would seek to quantify the share of Federal-Government-funded missions.

For this purpose, we utilize the FAA's Air Traffic Service Business Model (ATSBM), which in turn relies on data from the Traffic Flow Management System (TFMS) [26]. TFMS processes a variety of data sources and assembles them into a single record for each flight in the U.S. that flies under Instrument Flight Rules (IFR) and is captured by the FAA's enroute computers. The ATSBM model takes the TFMS flights and assigns them to 43 different user categories, one of which is air ambulance.^{***} For FY2023, ATSBM identified over 230,000 air ambulance flights, utilizing over 200 different aircraft types, including jets, turboprops, pistons, and helicopters.^{§§§} In addition, total unit operating costs (including fuel and oil, other variable costs, and fixed costs) are assigned to each flight based on numbers published in Conklin & de Decker's Aircraft Operating Cost and Performance Guide [27]. Table 4 shows summary totals for all air ambulance flights.

Table 4. ATSBM Air Ambulance Flights for FY2023 by Aircraft Type [27]

Type	Total Flights	Avg. Distance (miles)	Avg. Hours	Avg. Speed (mph)	Total Cost Per Hour
Jet	61,894	516	1.49	324	\$6,015
Turboprop	152,445	205	0.95	211	\$2,988
Piston	4,159	271	1.60	162	\$933
Helicopter	14,412	106	0.86	135	\$3,731
Combined	232,910	282	1.10	236	\$3,802

Helicopter costs are relatively high due to their high fixed and variable operating costs. In addition, the average distance travelled is much lower for air ambulance helicopters as compared to fixed wing aircraft. Thus, these data suggest that, at least initially, the opportunities for AAM vehicles (and particularly electric aircraft that have shorter range capabilities than hybrids) are likely to be targeted at patient transport services currently provided by conventional helicopters.

In the ATSBM model, the air ambulance category is simply considered part of the General Aviation (GA) user group for cost purposes; thus, the cited cost per hour in Table 4 is partially based on a variable cost per hour that does not account for any additional onboard personnel beyond the pilot. Therefore, the costs shown in Table 4 do not reflect much higher costs that may be specifically attributable to specialized air ambulance flights that typically require paramedic and/or EMT personnel on board. In addition, the fixed costs attributable to such flights may be quite high

^{***} A flight is assigned to the air ambulance category if it is flagged as a MedEvac flight in TFMS or if the flight operator is identified as an air ambulance entity.

^{§§§} The jet, turboprop, and piston categories are all fixed-wing aircraft.

due to low utilization rates. Accounting for these factors, a prior detailed air mobility study for NASA completed in 2018 suggests that the relevant costs for helicopter air ambulance flights is close to \$10,000 per transport [10].

Estimated Cost Assessment Utilizing AAM

Any cost assessment of an AAM mission development effort should consider both initial aircraft acquisition costs and associated operating expenses. The cost assessment for this effort is based on current market analysis of AAM aircraft that are advertised for patient transport and associated medical operations, but future aircraft designs may drive a different cost structure based on different system requirements that were not originally envisioned in this effort. The following subsections outline considerations regarding AAM aircraft acquisition costs and operating costs to support the VA patient transport application.

AAM Aircraft Acquisition Costs

Selling and leasing prices of AAM vehicles will obviously be influenced by overall vehicle characteristics, including (but not limited to) the design and complexity of the aircraft, the use of electric power or conventional fuel, battery size and capacity, autonomous features (if any), range, passenger and/or payload capacity, etc.

A useful starting point is to first consider published estimates of projected purchase prices for some vehicles currently under development. For example, Jump Aero is designing an eVTOL called the JA1 Pulse, which is tailored to short-range rapid response EMS in rural areas. Although this is specifically not the same focus as the short-range non-emergency VA transport mission being considered here, many of the characteristics of the Jump Aero vehicle overlap with the type of vehicle relevant for the ConOps in this patient transport application. The anticipated purchase price of the JA1 Pulse is \$1.8 million (within a “likely” range of \$1.6-\$2.5 million) according to a white paper published by the company in 2024 [28].

Archer Aviation is developing an eVTOL aircraft with six propellers to carry four passengers and a pilot. It is being designed to accommodate 20-50 mile trips within urban areas with a cargo payload of around 1,000 pounds. Called the Archer Midnight, it has an anticipated selling price of \$5 million [29]. Electra is another startup developing a 9-passenger eSTOL vehicle with a 3,000-pound payload and a range of up to 1,100 miles. Called the EL9 Ultra Short, press releases by Electra are consistent with an anticipated selling price of around \$4.5 million [30].

The suggested range of about \$2 to 5 million appears to be a sweet spot for many eVTOL vehicles.**** If accurate, such prices compare competitively with conventional helicopters. For example, the price of a light helicopter such as the Bell 407 is in the range of \$2.5-\$3 million, whereas a larger vehicle such as the Airbus H145 is around \$10 million (both of these vehicles are commonly used for EMS transport) [31].

Basing Costs

When considering the reference missions listed in this report, the addition of base stations for charging and/or maintaining electric vehicles is likely a necessary addition to future cost assessments. Further, although design considerations and requirements are outlined in EB 105A [32], they have yet to be officially assessed for development costs expected to be associated with future AAM operations. In the meantime, the cost of upgrading a current helipad to include electrification and required charging stations has been estimated in the range of a \$1.4 million investment (2021 prices) [33]. This is a starting point subject to potential escalation based on the location, whether an electric grid to support the charging stations is in place, and whether there is an established helipad. Additional costs will be expected from construction management, permitting, labor, and materials at the time of construction.

We note that the aforementioned NASA-funded urban air mobility study indicates that there is already a mature set of over 900 bases to support air ambulance and helicopter operations spread across the U.S. [10]. There is less coverage in rural areas where there may be an opportunity for AAM vehicles to fill in the gaps. When exploring the development of a new vertiport, it is expected that the full development costs may range between \$3.5 and \$12 million dollars, based on specific sites and if the vertiport is a ground-based vertiport versus developing a vertiport on top of an established VA medical facility [34]. For the reference missions outlined in this paper, it is expected that costs will be on the lower end of the spectrum considering the use of established VA medical facilities and leveraging local airports/helipads. As future AAM operations become more integrated into the national airspace system (NAS), it is expected that vertiports utilized for various mission profiles would support urgent and non-emergency patient transport missions; therefore, costs associated with the use of the vertiport would be comparable to current airport parking, fueling, and leasing fees.

**** The examples given here obviously do not cover the entirety of the relevant AAM space. As would be expected, cost estimates for some designs are quite speculative (if they exist at all). For example, ERC is a European-based company that is developing an eVTOL designed specifically for medical patient transportation; it allows for efficient stretcher loading for a single patient and in-flight care by an additional passenger. The current vehicle design has a projected range of about 110 miles and can fly for up to 60 minutes. To our knowledge, ERC has not released any cost estimates for their aircraft.

Operating Costs

The main competitive advantage foreseen for electric compared to conventional aircraft is typically in reduced operating and maintenance costs. Two of the key drivers of projected cost savings include lower maintenance costs for electric vehicles (due to fewer moving parts in the propulsion system) and the effective cost per mile or hour of electricity vs conventional fuel.

For example, Beta Technologies is developing both an eVTOL called the Alia A250 and an eCTOL called the Alia CX300 [35]. Both vehicles will be able to accommodate up to five passengers, will require a single pilot, and have a single fixed pitch propeller; the A250 VTOL will also have four lift propellers. Beta claims that hourly operating costs for the VTOL aircraft will be up to 40 percent lower relative to comparable non-electric VTOLs. Similarly, the operating costs for the CTOL variant are claimed to be up to 67 percent lower relative to comparable non-electric conventional aircraft. However, to our knowledge, Beta has not published further details to support these estimates.

The Jump Aero white paper [28] suggests direct operating costs of \$424 per flight for the JA1 Pulse vehicle. These operating costs are driven primarily by “battery reserve” costs that are supposed to reflect not only direct battery costs (including electricity) but also replacement at end-of-life. Other non-battery operational costs are included as “indirect costs,” which total \$685,000 per vehicle per year. These include items such as pilot and crew salaries, general and administrative (G&A) utilities, and maintenance, as well as more traditional overhead items such as aircraft amortization, insurance, and administrative overhead. The Jump Aero whitepaper appears to suggest that utilization rates will range anywhere from one operation every other day to as many as three per day in more populated areas.

If we use two operations per day as the average, this suggests total direct plus indirect operating costs of around \$1360 per operation for the JA1 Pulse vehicle (representing an AAM example). In comparison, using the data in Table 3, an example ground operation (weekday, with a stretcher, 50 miles, and a 30-minute wait) would be approximately \$380 and, using the data in Table 4, an example 1-hour air ambulance operation (using the “combined” data point) would be approximately \$3802. It is important to note that these estimates overall rely on a number of realistic but uncertain assumptions, including service pre-deployment of aircraft at existing general aviation (GA) airports, rural coverage areas, utilization rates, amortization costs, etc.

Other considerations in developing costs per mission will depend on the type of flight scheduling parameters, such as the number of ferry legs (positioning and de-positioning flights) required, and whether operations will be largely at existing helipads and field landings, or whether they will involve built for purpose landing facilities (such as vertiports), with attendant landing and handling charges reflecting the capital investment in those facilities.

As illustrated above, relevant cost estimates for services to be provided by AAM vehicles will depend on a detailed review of both their acquisition and operating costs and aircraft utilization, and the relationship between all of them. These conclusions are largely consistent with the aforementioned prior UAM market study performed for NASA in 2018, which concluded that eVTOLs are unlikely to compete with ground ambulances, but that eVTOLs and hybrid-electric aircraft could compete in the rotary wing market [10].

IV. Application 2: Organ Transport

A. Purpose and Scope

Our second selected application is Deloitte’s 10.8.2: Delivering organs for medical transplant (a.k.a. “Organ Transport”). Deloitte describes this application as the means to support delivery of critical organs needed for transplant. In organ transport, time is a critical factor to improve the outcome for patients. By using UAS as one of the means of moving organs from donors to recipients, hospitals and medical stakeholders could effect a more efficient, safer, and cost-effective means of organ transport.

Considerations for the organ transport application include the capability to cover the distance between donor and recipient facilities, safe storage of the organ, appropriate “hazardous material” protocols, and delivery time. In a recent review of organ transport challenges, the United Network of Organ Sharing (UNOS) stated that kidneys are the most transplanted organ, as well as the organ that travels most by commercial air. Currently, commercial air travel is the primary method of any long-distance organ transport, but it is quoted to be the least reliable [36].

Since organ procurement organizations (OPOs) rely heavily on commercial air transportation, they experience various complexities and errors in scheduling, maintaining correct chain of command to direct hand-offs,^{††††} as well

^{††††} In transporting organs, individuals generally serve as couriers to ensure the organ is moved where and to whom it should be. A hand-off between couriers may occur at various points, such as when modes of travel change.

as issues in accessing cargo offices of commercial air carriers for 24/7 organ deliveries^{****} [37].

The roles of the federal government in this application include maintaining the Organ Procurement and Transplantation Network (OPTN) and providing oversight and grant funding to Organ Procurement Organizations (OPOs). Although private medical networks have their own means of coordinating with OPOs, we focus on the VA as the priority federal agency for this application, as we did for the Patient Transport application earlier.

The VA's organ transplant mission is executed through its Veterans Health Administration (VHA) network of transplant centers. All VA transplant programs are members of the national OPTN under the National Organ Transplant Act of 1984 [38]. VA facilities comply with OPTN bylaws and federal transplant regulations just like civilian centers [39]. At a high level, the steps followed to transport an organ are:

- **Step 1 – Transplant Approval:** Upon organ availability, transplant teams (VA surgeons or OPO coordinators) confirm suitability and “arrangements are made to procure, transport, and store the donated organ, and for the transplant candidate to travel to the transplant center for surgery [40].”
- **Step 2 – Organ Transport Management:** Organ transport is managed by the OPO or affiliated couriers. Once a donor organ is recovered (at a VA or non-VA hospital), certified OPO staff or contracted medical couriers promptly arrange travel to the transplant center.
- **Step 3 – Transport Mode Selection:** The next step is to select an appropriate mode of transport for the patient and/or organ, depending on the most efficient means to connect the organ with the receiving patient. Considerations include:
 - **Level of urgency.** For urgent cases, the VA can prioritize direct airlift for short distances to avoid delays. The guiding rationale is organ viability and patient outcome.
 - **Cold ischemic time limits.** The cold ischemic time (CIT) of organs is defined as the time period from when a donor organ stops receiving blood from the donor patient to when it is reconnected to a receiving patient's blood supply to complete the organ transplantation [41]. Minimization of the organ's CIT is vitally important. Organs that require continuous fluids or oxygenation of the tissues will require the use of a warm perfusion machine, which can increase the time outside of the body by six to 12 additional hours, where most organs/solid tissues are only viable in cold storage for six to 30 hours [42]. Table 5 lists the most common organs transported for transplantation services and the average limits of CIT for each.

Table 5. Average CIT Limits of Most Commonly Transported Organs [43], [44]

Organ	CIT Limit (hours)
Heart	6
Lungs	6
Liver	12
Pancreas	18
Kidney	36

- **Within region or inter-region transport.** For transportation of organs within the same region, a ground courier or ambulance is the preferred option whereas an organ from another state typically utilizes air travel booked by the OPO. Certain organs with low CIT limits typically use air charter or MedEvac. Table 6 summarizes typical organ transport logistics.

^{****} Organs are sometimes transported in the cargo hold of aircraft; because airline cargo offices are generally only open during regular business hours and flights often occur outside of these time windows, there can be instances where the organ cannot be picked up because the cargo office is closed.

Table 6. Typical Organ Transport Logistics by Mode [45], [46], [47]

Mode	Vehicle	Trigger(s) for Mode	Crew/Team & Required Systems	Travel Distance
Ground	Ambulance	<ul style="list-style-type: none"> Within a medical network or between proximate hospitals. Extremely time-sensitive transplantations (i.e., hearts, blood transfusions, etc.), where warm perfusion technology can be used to help increase the viability of the organ. 	<ul style="list-style-type: none"> Surgical team for removal and placement; this team rides along with the organ. EMS Crew to drive the ambulance. 	Short (5 – 50 miles)
	Regular Automobile (car, van)	<ul style="list-style-type: none"> Transfers over short distances when the organ can remain viable with cold storage. Best for blood and tissue transfers or for research purposes where a patient is not waiting for the transfer. 	<ul style="list-style-type: none"> Research team, medical team, or courier. Driver, which can also be a member of the research or medical teams. 	Short (5 – 50 miles) or Medium (50 – 150 miles)
Air	Helicopter	<ul style="list-style-type: none"> Emergency situations where transplantation is required over short to medium distances 	<ul style="list-style-type: none"> Surgical team for removal and placement; this team may ride along with the organ Takeoff/landing pads at hospitals used if available 	Medium (50 – 150 miles)
	Commercial Aircraft or Charter Aircraft (if commercial flight is not available or timely)	<ul style="list-style-type: none"> Emergency situations where transplantation is required over long distances or when specialty transplant centers are required for the procedure. Cold storage or warm perfusion systems can be used, but require strict hand-off procedures due to the multiple personnel involved (e.g., medical staff, courier, TSA, airline cargo staff) 	<ul style="list-style-type: none"> Surgical team for removal and placement; this team may ride along with the organ. Courier for organ transport Aircraft crew/cargo staff/airline personnel EMS Crew to drive the ambulance to/from airports. 	Long (150+ miles)

B. Description of Application and its Missions

The envisioned use of UAS for organ transport encompasses two mission examples:

- Using a UAS to cover short distances (5 – 50 miles) for moving an organ on “first-mile” and/or “last-mile” legs to connect to other modes of transportation, and
- Using a UAS with greater range to cover short or medium distances (5 – 150 miles) for moving an organ between locations within a medical network.

No mention of the size of the UAS is provided here because the upcoming FAA 14 CFR Part 108 may obviate the need to strictly distinguish between use of “small” (< 55 pounds) and larger UAS. Additionally, small UAS (sUAS) are likely incapable of providing sufficient payload capability to perform some organ transport missions due to the weight of commercially available organ transport containers, which are generally on the order of 10 – 100 pounds. Containers on the low end of the size range that may be feasible with sUAS resemble little more than coolers for cold storage, and heavier containers generally provide improved cold storage or automated perfusion capabilities [48], [49], [50]. More advanced perfusion capabilities can require even larger and heavier storage containers, and some organ transports require a surgical team to ride along with the organ. Missions requiring beyond approximately 100 pounds of payload in practice will be very similar to the Patient Transport application discussed previously in Section III; therefore, we focus our discussion here on storage systems in the lower- to middle-portion of the storage size range, from approximately 10 – 50 pounds.

In the current state, the high-level concept of operations for both organ transport missions starts with the hospital receiving a demand for an organ. Once an organ is identified, the procurement team is notified and dispatched from the starting location by ground transportation. While potentially encountering ground traffic, the procurement team travels to the harvesting site where the donor organ is located and the organ is evaluated to determine suitability. Once approved, the procurement team notifies the medical team at the recipient site. The organ is harvested, then properly

stored and loaded onto the ground transport with the procurement team. The team then travels to either the airport (Mission 1) or the recipient medical site (Mission 2) for delivery. Upon arrival, the organ is transferred to courier at the airport (Mission 1) or the recipient medical team for the medical operation (Mission 2).

Mission 1: First-Mile / Last-Mile Organ Transport

In the future state of this mission, a UAS replaces a ground vehicle in fulfilling the first-mile and/or last-mile stage (nominally 5 – 50 miles) of an organ delivery to help shorten the overall transport time and CIT. The trigger for this mission would be when the need for organ transport is directed by the National Organ Registry. Operating under 14 CFR Part 108 rules, a UAS would be loaded with the organ and sent from the donor hospital to a local airport where a courier would be waiting to receive the organ for either a charter or commercial flight for a regional or cross-country delivery. On the other end of the journey, once the charter or commercial flight lands at the destination airport, a courier would then place the organ and associated medical systems in an appropriate cargo container on another UAS that would directly take the organ to the receiving hospital.

The use of a UAS would shift at least one leg of ground transportation to the air (it is not required that both the first-mile and last-mile legs be shifted) in the regional or cross-country delivery (≥ 150 miles between donor and recipient) of the organ. In bypassing busy urban surface traffic, the CIT is potentially shortened and thus the viability of the organ is increased.

Mission 2: Intra-Network Organ Transport

In the future state of this second mission example, the UAS completes the full round-trip delivery of the organ within a medical network (nominally 5 – 150 miles), substituting for a ground vehicle. The UAS would operate under the upcoming 14 CFR Part 108 rule for medium distance transportation as a Beyond Visual Line of Sight (BVLOS) operation. As with Mission 1, the trigger would come from the National Organ Registry and/or local hospital personnel managing the organ transplant. This mission begins when a hospital identifies a procured organ that may require a shorter transportation time than could be achieved by standard ground transportation. The hospital would dispatch a procurement team to meet at the site of the donor organ to verify that it meets the necessary patient requirements. While the team verifies patient requirements, a UAS would be waiting at the donor hospital to transport the organ. Upon approval from the procurement team, they would recover, package, and place the organ in an appropriate cargo loader on the UAS. The UAS would then fly to the receiving hospital where a separate retrieval/surgical team would unload the organ and do a secondary verification for patient transplantation.

As in Mission 1, using the UAS for transporting the organ would help in reducing the CIT by replacing ground transportation from donor to recipient in regional deliveries.

C. Technical and Operational Requirements

The FAA has specific requirements for package and baggage handling which extend to the handling of organs on commercial and charter flights [51]. Although it is unclear what requirements will be for UAS organ transport operations, specific technical and operational requirements for 14 CFR Part 121 organ transport may provide a starting point, and these are provided in Ref. [3].

Landing Zone Requirements

It is expected that as hospitals and VA organ transplantation centers start to investigate organ transport via UAS, they will use already designated “Emergency” transportation zones for organ delivering/receiving (i.e., near helipads for MedEvac helicopters or near ambulance parking areas). Currently there are no federal regulations directing the design or size of a UAS landing zone, but the following are considerations that should be made at a hospital or VA facility for the purpose of organ transport:

- **Avoid hazards:** When considering co-locating a UAS landing zone with a currently operating MedEvac helipad, the UAS landing zone must be clear from the helicopter’s takeoff/descent trajectory and not located within the path to entry into the medical facility when the helicopter is loading/unloading. Tie downs should be included to prevent the UAS from being blown away from rotor down-wash.
- **Space to load organ/supporting systems:** The UAS landing zone must have enough space surrounding it to be able to load and unload the organ, associated packaging, and supporting systems without causing damage to the organ or UAS.
- **Appropriate storage of UAS when not in use:** Most UAS are built from carbon fiber and other materials not suitable for long durations in wind, direct sun, or rain. When not in use, the UAS should be stored in such a way that prevents deterioration of flight-critical components and routinely maintained for safe and reliable operations.

Aircraft Design Requirements

Fixed-wing aircraft generally have longer endurance/ranges than pure rotorcraft/multirotor aircraft, and some UAS currently being tested in healthcare operations can take off and land vertically but transition to horizontal flight for efficiency and endurance purposes. The UAS marketplace continues to evolve in this domain and hybrid VTOL/fixed-wing aircraft with moderate range/endurance will likely be a useful candidate for this mission. Additionally, the landing zone and supporting infrastructure will drive the choice of UAS design.

As mentioned above, the UAS will require cargo bays that can hold the appropriate packaging and supporting systems of the transported organ. In some instances, different UAS could be used based on if the organ is traveling with a supporting system. Therefore, some hospitals or VA centers may have a fleet of UAS based on the type of organ, supporting systems required, and transport range. §§§§

Handling qualities of the UAS and thermal conditions of the cargo bay must be tested to verify that the organ is maintained structurally and thermally. Although we expect that the organ will be packaged with ice packs and other packaging materials to maintain its temperature, the internal temperature of the cargo bay should not significantly change the CIT of the organ.

We expect that with these operations occurring in compliance with 14 CFR Part 108, certification of the UAS will be directed by the regulations within that rule once it is published and compliance dates are established.

Crew Requirements

The UAS aircraft crew will need to hold First- or Second-Class FAA medical certification for operations of medical transport, unless future UAS regulations state otherwise for 14 CFR Part 108 or medical operations. Specific training that may be required in any future iteration of the organ transport application includes the following, which are necessary today for air ambulance pilots [52]:

- Terrain and weather avoidance maneuvers
- Infection control and safety protocols for organ packaging and storage on the UAS
- Aircraft systems, both aviation and non-aviation (e.g., organ support systems, radios)
- Organ loading and unloading procedures
- Flight planning and coordination with VA hospitals, EMS agencies, ATC
- Regular training for operating procedures, VA patient plans, flight hazards, etc.

If nighttime operations are planned, specific training for crew and other personnel may also be required.

UAS 3rd Party Service Providers & Remote Operations Centers Requirements

With the expected adoption of 14 CFR Part 108 and the associated 14 CFR Part 146, UAS Automated Data Service Providers (ADSPs) will need to be specialized to support the VA and OPOs for organ transport operations, including considerations for organ-transport-specific data to effectively enable flight planning coordination and safe operations [53]. When considering BVLOS operations, some UAS organ transport missions may need to fly above 400 feet (outside of Class G airspace), requiring coordination with ATC for specialized medical flight designations and clearances which may be facilitated by ADSPs [54]. ADSPs and Remote Operations Centers (ROCs) established for organ transport should be specialized in medical transport and have dispatchers and systems that are able to communicate effectively with local medical staff and OPOs to verify correct digital security and flight planning of the organ through both Mission 1 and 2 scenarios [55].

The following are additional considerations for UAS organ transport operational environments:

- ***Shared Flight Safety Responsibility between Stakeholders:*** Each organ transport operation that will use an ROC will require at least one qualified staff member who is educated in medical transport logistics and terminology to communicate effectively with the medical retrieval and recipient teams. Additionally, the ROC may be required to communicate with OPO staff to coordinate travel distances and locations to minimize the organ's CIT. The ROC will be responsible for communicating with the pilot in command (PIC), who is likely to be located at the ROC, and hospital staff for landing and loading/unloading of the organ. The ROC may require associated crew resource management (CRM) support in high-workload situations or when multiple organs are being delivered to/from multiple locations.
- ***Supporting Standard Operating Procedures:*** SOPs will be required for associated training, operational performance metrics and for review by the FAA and VA for auditing purposes. Additionally, to support organ transport decision-making, SOPs will direct future selection of UAS aircraft for given missions if a VA facility is able to support a fleet of vehicles with various payload capacities, various range envelopes to serve different

§§§§ Some organ transports require a surgical team to ride along with the organ. In these cases, the requirements mirror those of the patient transport application discussed previously (in Section III), and Part 108 UAS operations are not applicable.

facilities, and/or multiple authorizations/certifications of aircraft and personnel based on the mission profile (i.e., Mission 1 or Mission 2 flight profiles).

- **Technology & Communications for Improved Situational Awareness (SA):** Like an air traffic control tower, the ROC will be required to use technology and communication means to provide in-time SA to pilots and VA medical staff. These technologies and communication methods should be applicable for the missions of a given VA medical facility to facilitate entry and exit of the aircraft at the hospitals or landing zones. Additionally, in times of surge missions across the VA network of facilities, ROCs will need to be interconnected to each other to be able to spread missions across multiple medical facilities.

D. Assumptions

The assumptions outlined in Table 7 support a ConOps in which the VA integrates AAM solutions (i.e., UAS) and novel operational models for organ transport.

Table 7. Assumptions for Organ Transport Missions

Assumption Category	Assumption
Aircraft Certification and Availability	UAS will be certified and operational for long-distance package delivery, with appropriate medical warning labels. Though we expect operations under 14 CFR Part 108, if operations are conducted under 14 CFR Part 135, then associated Pipeline and Hazardous Materials Safety Administration (PHMSA) standards apply for medical equipment transport, and it is possible that these standards will be applied to future 14 CFR Part 108 operations also.
Payload & Containment	Organ containers are expected to be in the range of 10 - 50 pounds based on current dimensions and designs [49]. Large (i.e., other than “small”) UAS are assumed to be able to accommodate containers on the heavier end of this spectrum, which may be equipped with automated organ preservation systems.
Delivery Range	Mission 1 (first-mile/last-mile): 5 – 50 miles; Mission 2 (intra-network): 5 – 150 miles
Dispatch Readiness	Aircraft can be rapidly deployed due to electric propulsion (minimal startup time) and specialized use (i.e., not designated as a multi-use UAS for other types of package delivery).
Turnaround Operations	Turnaround time between missions is manageable via battery swap or fast charging, enabling multiple daily flights.
Medical Storage Environment	Aircraft can provide thermal and shock control, consistent with cold ischemia or normothermic transport.
Handling & Handoff, Crew	Assumes the system has SOPs in place for sterile transfer and chain of custody logging between VA centers, couriers, and flight crews.
Landing Infrastructure	For Mission 1: Local airports may include a UAS landing zone specific for organ delivery and pick-up that separates the operation from current cargo operations. For Mission 2: Urban VA sites use current emergency zones to incorporate a UAS landing zone. Rural sites may also use current emergency zones, or establish new UAS landing zones, if spacing permits.
Charging Infrastructure	Charging or battery swap capabilities assumed at landing zones (e.g., power carts or fixed chargers). Battery swaps are possible, but it is more likely that charging pads for organ transport UAS will need to be installed at medical facilities and/or airports.
Airspace Access and Management	Missions will have access to low-altitude airspace and avoid restricted zones or manage them via corridors. UAS will need to operate in accordance with TFRs and will need flight plans that do not interfere with the typical approach/departure paths of large commercial airliners.
Weather Operations	Missions are performed in both visual and instrument meteorological conditions. UAS will not operate in severe weather conditions (e.g., storms, icing), and backup transport options are assumed in these cases.
Terrain Considerations	Organ transport is expected to end at a medical facility; therefore, flying over various terrain conditions should not impede the operation. Sensor packages are expected to be installed on the UAS to prevent any terrain collisions.
Funding	The VA covers costs through internal budgets or reimbursable arrangements with insurance providers of the patients for delivery operations and associated staff involvement.

E. Cost Assessment of Organ Transport

Regardless of the transport mode(s) used, it is important to recognize that the direct cost of transporting organs is likely to be a small fraction of the overall organ procurement costs incurred by OPOs. For example, a study published in 2021, using data from 51 of the 58 OPOs nationally, estimated that transport costs for kidneys from deceased donors represented about 7.5% of the direct procurement costs (\$1,200 out of \$15,998 total direct), and a little over 3% of

total procurement costs (\$1,200 out of \$35,400 direct and overhead) [56]. Combined with the fact that time is such a critical factor in organ transport, it is reasonable to presume that relative transport costs may not be a primary driver of AAM adoption. Nevertheless, it is useful to start by assessing the costs of current organ transport modes.

Current Costs of Ground Transport

In scenarios involving ground transport (directly from the donor site to the transplant site or last-mile transport to/from an airport or heliport), there are private courier and ambulance companies that can provide dedicated ground delivery services for organ transport. Although it is difficult to obtain specific cost estimates, one simplistic but reasonable method to get a probable lower bound on ground transport costs is to consider the quickest “overnight” shipping solutions from a conventional shipper such as FedEx or United Parcel Service (UPS). As an example, if using a commercial kidney transporter container weighing 45 pounds, we found the cost of FedEx’s highest priority shipping service for a 25” x 25” x 25” container of that weight to be close to \$500 for short-haul trips that range anywhere from 20 to 80 miles [49], [57]. This is likely to be a very low minimum bound on relevant transport costs as it does not include explicit continual oversight and/or monitoring that is often desirable for organ transport.

Current Costs of Air Transport

There will be a large effect on air transport costs depending on whether an organ is shipped as cargo on an existing scheduled service or via chartered aircraft. Rates for cargo (below the wing) on a scheduled flight can be quite inexpensive; for example, using the online calculator for American Airlines, a single box weighing up to 50 pounds can be shipped across the country for less than \$150. Paying the full cost for a chartered or air ambulance flight is much more expensive. As previously described above in Table 4, systemwide average costs for air ambulance flights range from a little over \$900 per hour for piston aircraft to over \$6,000 per hour for jets. Based on these estimates alone, we can expect that, purely from a cost perspective, UAS (which will likely have much lower direct operating costs than conventional charter aircraft) could be well positioned to be successful in providing organ transport services in cases where air ambulance services (or charter services operating MEDEVAC flights) are required.

Estimated Cost Assessment Utilizing AAM

Functionally, the primary advantage for drone transport relates to *time* rather than *cost* savings. This is an overriding consideration given the maximum CITs, as defined previously in Table 5. That said, more organs may be able to reach more people because using UAS allows them to be moved more quickly. From a cost perspective, this may enable fewer organs to be “wasted” thus enabling lower costs per organ transplant overall (even if the direct transport cost is not less using a UAS).

To get a sense of the potential costs involved in procuring and operating UAS for organ transport, we can initially look at currently available drones with sufficient payload capacity and range. To do so, attention is focused on drones with a range of at least 20 miles and a payload capacity of at least 50 pounds. These payload and range requirements together actually exclude most current commercially available UAS (many may satisfy one, but not both criteria), but four examples (at different stages of development) were considered, depicted in Table 8.

Table 8. Examples of Drones for Potential Organ Transplant [58], [59]

UAS Characteristic	Ehang EH216-S	Jouav CW-80E	Defour Aero2	Elroy Chapparral
Design	Multirotor eVTOL	Fixed Wing VTOL Hybrid-electric	Tilt Wing VTOL Hybrid-electric	Fixed Wing eVTOL
MTOW (lb)	1325	240	460	1215
Payload (lb)	485	55	115	500
Range (miles)	22	62	250	300
Cruising Speed (mph)	62	56	150	143
Fully Loaded Flight Time (min)	21	<i>Unknown</i>	180	<i>Unknown</i>
Price (\$)	\$410,000	\$150,000	<i>Unknown</i>	<i>Unknown</i>
Current/Projected Primary Uses	Passenger transport; Logistics	Mapping; Surveillance; Emergency Response	Cargo Transport	Cargo Transport

Unit Cost Estimates

The following UAS cost assumptions use the parameters shown above in Table 8 as a starting point and then make various adjustments based on range capability and other factors:

- **Average Flight Duration/Distance:** 60 minutes / 60 miles^{*****}
- **Annual Number of Flights:** 200 (assumes out and back for 100 organ transports)^{*****}
- **Expected Lifecycle:** 2-4 years
- **Acquisition Cost:** \$200,000-\$400,000
- **Energy Use:** 20-25 kWh per flight (estimate partially derived from Ehang reported battery size of 17 kWh for EH216-S vehicle with large payload capacity but very short range)^{††††}
- **Electricity Cost:** 13.48-13.77 cents per kWh (U.S. averages for 2025-2026 from US Energy Information Administration (EIA)) [60]
- **Annual Insurance Cost:** \$17,500-\$25,300 assuming base premium of 3% of drone value, \$7440 flight risk and liability; plus 30% add-on for payload insurance, heavy lift, and related capabilities [61]
- **Annual Maintenance Cost:** \$6,000-\$18,000 (assumes 50 percent markup from estimates given in [62] based on large weight and range requirements)
- **Other Overhead (including remote pilot) and Profit:** 25% of all other cumulative costs

With these assumptions, the range of estimated costs are shown in Table 9. The total fully loaded cost per 1-hour flight is estimated at \$500-\$1,500; thus, the relevant cost for each transport including the return to base is double that, or \$1,000-\$3,000. These are notional costs given the large uncertainties regarding design, market pricing, and unknown future certification and production approvals that would be needed from FAA.

These estimates may be somewhat optimistic since they do not consider other potential infrastructure costs associated with storing or staging vehicles at specific locations. On the other hand, direct vehicle acquisition and operating costs may well decline in the future as better battery and flight technologies are developed, and as remote piloting technologies and regulations allow a single pilot to control multiple vehicles simultaneously. As a point of comparison, the estimated average hourly cost of current air ambulance transport options (as shown in Table 4) ranges from \$933 for piston aircraft to \$6,015 for jet aircraft.^{††††}

Table 9. Life Cycle and Per Unit Cost Estimates

Cost Variable	4-Year Lifecycle (800 Flights) with Lowest Range of Costs	2-Year Lifecycle (400 Flights) with Highest Range of Costs
Acquisition Cost	\$200,000	\$400,000
Electricity Cost	\$2,200	\$1,400
Insurance Cost	\$70,000	\$50,600
Maintenance Cost	\$24,000	\$36,000
Total Lifecycle Cost	\$296,200	\$488,000
Direct Cost per Flight	\$370	\$1,220
Other Overhead	25%	25%
Total Cost per Flight	\$500	\$1,500
Total Cost per Roundtrip	\$1,000	\$3,000

***** Reference [3] provides additional information on the selection of the average flight distances and number of flights for the cost estimates; these values are relatively uncertain at this stage.

††††† Direct electricity costs, regardless of the uncertainty in actual energy use per flight, will be a very small portion of total costs.

††††† Unlike the dedicated UAS scenario, these estimates for current flying options do not presume that they must dead-head back to their original location. For helicopters specifically, the count and distribution of existing bases described in Ref. [3] support the reasonableness of this assumption.

V. Potential Future Research

There are many potential avenues that could be taken in future research to further vet the two applications described, sharpen the assumptions based on emerging data on new eVTOL and UAS vehicles, and explore specific mission examples.

One such path could be performing conceptual design of an aircraft to perform one or multiple of the missions described above. To provide a rough estimate of what might be required for an aircraft designed for the patient transport mission, a simple “back-of-the-envelope” aircraft sizing is described here. Since most eVTOL aircraft are designed for smaller payloads than noted in Table 2, it is anticipated that an eVTOL aircraft specifically designed for the patient transport mission as described above would be larger than many existing concepts.

To develop a rough estimate of the aircraft size, we leverage a simple sizing approach that iterates on the weight equation, leveraging the Breguet range equation to estimate the cruise energy requirements and actuator disk theory to estimate the takeoff and landing energy requirements for an all-electric VTOL aircraft. The weight equation for a battery-electric aircraft is expressed as Eq. (1), where $W_{payload}$ is the total payload weight (including crew), W_{bat}/W_0 is the battery weight fraction, and W_e/W_0 is the empty weight fraction.

$$W_0 = \frac{W_{payload}}{1 - (W_{bat}/W_0) - (W_e/W_0)} \quad (1)$$

The electric Breguet range equation [63] can be solved for the battery weight fraction required for cruise as shown in Eq. (2), where R is range, $(L/D)_e$ is the equivalent lift-to-drag ratio (which is the lift-to-drag ratio times propeller efficiency for an airplane), $(W_{bat}/W_0)_{cruise}$ is the battery weight fraction for cruise (i.e., ratio of the battery weight required to fly the range R to the gross weight), e_{bat} is the specific energy of the battery pack, g is the acceleration due to gravity, and η_{elec} is the electrical system efficiency.

$$(W_{bat}/W_0)_{cruise} = R / \left[(L/D)_e (e_{bat}/g) \eta_{elec} \right] \quad (2)$$

To determine the battery weight fraction for the takeoff and landing portion of the flight, we assume the energy requirements can be effectively approximated by the hover (out of ground effect) power required over a period of time. Momentum theory indicates the power required for hover is given by Eq. (3) [64], where FOM is the figure of merit, T is the thrust, ρ is the atmospheric density, and DL is disk loading.

$$P_{hover} = (T/FOM) \sqrt{T/2\rho A} = (T/FOM) \sqrt{DL/2\rho} \quad (3)$$

The weight of the battery needed for hover can be found by multiplying the mass of the battery required for hover times the gravitational acceleration, and the mass of the battery required is the energy required for hover divided by the specific energy of the battery times the electrical system efficiency. Furthermore, since the energy required for hover is the power required in hover times the time in hover, the battery weight required for hover can be expressed as Eq. (4).

$$(W_{bat})_{hover} = (m_{bat})_{hover} g = (E_{hover} / [e_{bat} \eta_{elec}]) g = ([P_{hover} t_{hover}] / [e_{bat} \eta_{elec}]) g \quad (4)$$

Combining Eqs. (3) and (4) yields Eq. (5).

$$(W_{bat})_{hover} = (T/FOM) \sqrt{DL/2\rho} (t_{hover} / [e_{bat} \eta_{elec}]) g \quad (5)$$

Recognizing that the thrust must be equal to weight for hover enables us to solve Eq. (5) for the battery weight fraction required for hover as shown in Eq. (6).

$$\left(\frac{W_{bat}}{W_0}\right)_{hover} = \left(t_{hover}/FOM\right) \sqrt{DL/2\rho} \left(g/[e_{bat}\eta_{elec}]\right) \quad (6)$$

The total battery weight fraction required in Eq. (1) is then found from the sum of the cruise and hover battery weight fractions determined by Eqs. (2) and (6), respectively. The variables required in Eqs. (2) and (6) are assumed known from either the mission requirements, technology assumptions, or as high-level design parameters for an aircraft. To determine the aircraft size, an initial guess of the gross weight is made

To determine the aircraft size (gross weight), the remaining parameter necessary to estimate (in Eq. (1)) is the empty weight fraction. Typical early-phase sizing studies leverage historic regressions of aircraft empty weight fractions to estimate the empty weight fraction. Since there are no certified eVTOL aircraft yet developed from which an empty weight fraction regression can be made, we estimate a constant value here. For conceptual aircraft developed in NASA's Revolutionary Vertical Lift Technologies project, empty weight fractions vary between approximately 0.6 and 0.85 [65]. A survey of a few industry eVTOL concepts by Das Biswas indicates empty weight fractions between 0.46 and 0.65 [66]. McDonald and German, in performing similar simplified analyses, assumed a constant 0.55 empty weight fraction [67]. Based on these values, we assume a constant 0.58 empty weight fraction for our simple study here.

Now we can estimate the size of aircraft required for the patient transport mission by taking the mission requirements of 2,000 lb payload, a 100-mile range plus a 30 min cruise reserve (assuming operations during the day under visual flight rules for an airplane), and 120 seconds of hover time, which is taken from Ref. [68] that describes a nominal UAM mission. Other required assumptions are that the aircraft has an equivalent lift-to-drag ratio of 10, which is slightly higher than the concepts in Ref. [65] but in line with values assumed in Ref. [67]; a cruise speed of 150 mi/hr; a 15 lb/ft² disk loading, which is in line with Refs. [65], [66], and [67]; a 0.7 figure of merit, which is in line with Refs. [65] and [67]; a 90% electrical system efficiency; a 400 Wh/kg battery pack specific energy; sizing the aircraft assuming only 80% of the total energy in the battery pack is available to account for battery degradation over time and the desire to avoid operating with a very low state of charge; and a takeoff/landing altitude of 3200 ft, which Ref. [68] indicates as a reasonable value for operations in many places in the US. These parameters yield an estimated aircraft gross weight of approximately 16,100 lb. If the payload is increased to 3,000 lb, the estimated weight grows to approximately 24,100 lb.

These weights are significantly heavier than most UAM aircraft concepts, which generally range from around 3,000 to approximately 9,000 lb [65, 66], and they are the result of increased payload and range requirements. To illustrate how aircraft size changes with mission requirements, Fig. 2 shows the sensitivity of the estimated gross weight to changes in the payload and range requirements (assuming all other parameters are held constant).

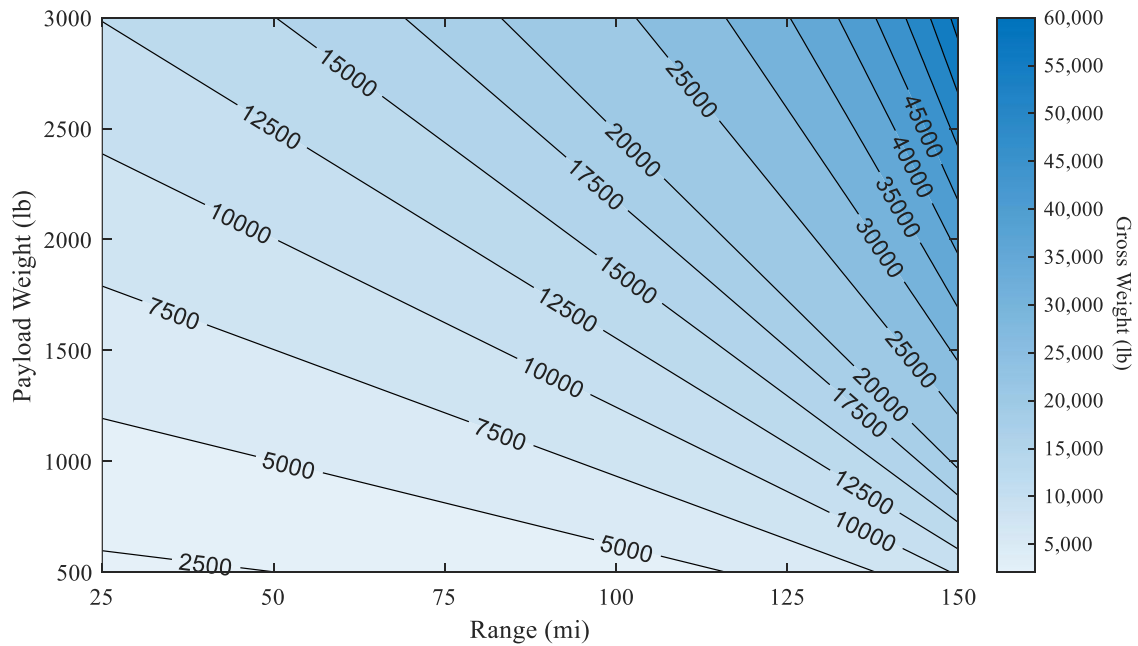


Fig. 2 Sizing estimates for a national eVTOL aircraft over a variety of payload and range requirements.

Many UAM aircraft are designed for 4-6 passengers (approximately 800-1200 lb payload) and ranges of around 50 to 100 miles, and the aircraft weights predicted by this simple method vary from approximately 4,000 lb to about 9,600 lb for these cases, which is in line with the weights of many UAM aircraft noted above. At the higher payload weights shown, which are representative of those believed to be required for widescale deployment of the patient transport application, the vehicle gross weight shows a higher sensitivity to increased range than at lower payload weights, which indicates that the patient transport application will be more challenging for eVTOL aircraft to effectively serve than air taxi UAM missions.

Future studies could leverage such simple sizing methods as a starting point for more detailed analyses of aircraft purpose-designed for the patient transport application. Alternatively, analysis of how many patient transport missions could be served by eVTOL air taxis currently under development could be performed to ascertain how significant of a limitation the lower payload capabilities of those aircraft would be for practical operations. Additionally, aircraft designs could be explored for the organ transport application and compared to other UAS designs that are geared toward other package and cargo delivery missions. Such work would provide useful information for the VA and other healthcare providers in assessing the feasibility of performing patient and organ transport with AAM assets.

VI. Conclusions & Recommendations

AAM applications hold the promise of advancing technology and means to better serve the public in addressing transportation challenges. Our effort started by reviewing prior analysis that had identified a set of public good applications, to which we added several new ones. We then developed and applied a structured, repeatable process to down-select applications for deeper analysis. That process identified critical gaps and opportunities where AAM solutions could enhance patient outcomes for two medical transport applications: Patient Transport and Organ Transport. We further focused our analysis on the air medical operations (with supplemental ground transportation, when deemed appropriate for either time or cost characteristics) within the VA healthcare system as a particular federal government stakeholder.

In our first chosen application, patient transport using an AAM vehicle, the current state is marked by patient transfers being predominantly conducted via ground transportation. Such transfers are constrained by limited access to VA members and the absence of a dedicated VA-owned vehicle fleet. Most VA patient transports are conducted via volunteer transportation programs, which do not always provide consistent means of transportation, particularly for rural VA patients—travel distances for rural patients to specialized care facilities can often exceed 100 miles. When exploring interfacility transfers, cost continues to be the driving factor on patients' transportation in non-emergency and urgent scenarios.

In our second chosen application, organ transport using UAS, we found that the current state of organ transport has faced increasing scrutiny and federal oversight due to inefficiencies and delays associated with commercial airliner use. Congressional directives, modernization efforts by the Department of Health and Human Services, and recent publications from industry working groups tasked to explore means to improve organ transport have all underscored the urgency to explore other means and systems for improved transportation. Our analysis shows potential for UAS-based organ transport to improve first-mile/last-mile and intra-network missions.

The expected benefits of AAM for these applications center around improved speed relative to ground transportation and reduced operating costs relative to current air transportation, though we note that, because these aircraft are still in development, our cost estimates are approximations based on very limited data. We also identified several barriers for near-term deployment. Aircraft certification, infrastructure readiness, and medical standards compliance for these new aircraft platforms are significant hurdles for industry OEMs. Accordingly, forecasting scalability and affordability for the VA is challenging to determine currently. Pilot programs, such as the AAM and eVTOL Integration Pilot Program [69], could help efforts to validate operational feasibility and financial sustainability.

Based on our assessment of the current industry environment for public good AAM applications, such as the two analyzed in this report, we recommend strategic partnerships among the VA, OEMs, and private healthcare providers to support pilot programs. Federal support from agencies such as the DOT and the VA, either through regulatory policy or grant funding, would further accelerate adoption. Infrastructure investment would also be beneficial. By leveraging compliance to EB105A and other guiding FAA policy, existing helipads and airports could provide initial entry for the proposed medical applications, leading to future use of dedicated vertiports and charging/landing pads for both crewed and uncrewed aircraft.

Technology enablers—including advancements in battery systems, autonomous flight capabilities, noise reduction, and digital infrastructure (e.g., UTM)—are areas in which NASA, other federal partners, and industry

stakeholders can support these progressive integration efforts. However, long-term operational sustainability will depend on the development of cost-effective models that align with the VA’s future budget and resources. Fiscal constraints may hinder direct VA operations or procurement of AAM aircraft for the two chosen applications, which would likely necessitate other operational models, such as contracting and partnership models with OEMs and operators.

We identified key end users to include public and private healthcare systems, OPOs, medical networks, and patient populations. To support the integration of AAM into existing healthcare systems, we recommend the following next steps for NASA:

- **Support the implementation of pilot programs** at select VA networks and transplant hubs, leveraging existing helipads/airports first.
- **Assist the VA in assessing charging infrastructure requirements** for UAS/AAM landing zones at hospitals and clinics based on NASA’s UAS/AAM expertise.
- **Partner with the VA and/or other organizations involved with organ transport to study organ handling characteristics** on UAS platforms.
- **Engage in industry standards development** to inform UAS design, handling, and operational requirements, supporting compliance pathways for 14 CFR Part 108 and 14 CFR Part 146 when they are finalized.
- **Collaborate with AAM OEMs** to identify integration needs, such as autonomous operations, communications between vehicle and automated data service provider(s) (ADSP), and landing zone requirements.

In conclusion, AAM holds potential for improving veteran healthcare access and outcomes. These patient and organ transport public good applications represent likely viable, beneficial avenues for the federal government to demonstrate initial AAM operations to help the industry learn and mature.

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