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NASA Electric Vertical Takeoff and Landing (eVTOL) Aircraft Technology for Public Services – A White Paper

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Foreword

In 2014, the Vertical Flight Society (VFS) organized a series of workshops on Transformative Vertical Flight (TVF) in collaboration with NASA, the American Institute of Aeronautics and Astronautics (AIAA) and the Society of Automotive Engineers (SAE). The intent was to build a community of aerospace professionals that included technical, regulatory, and business elements, organized into several working groups, to explore potential future air transportation systems with innovative vertical takeoff and landing (VTOL) aircraft. Between 2014 and 2020 the annual TVF workshops focused on systems that embody combinations of on-demand, electric and hybrid-electric propulsion and vertiport-capable configurations and designs while identifying areas of potential interdisciplinary collaborations and solicited expert opinions from the participants on the work and timeframes required to transform air transportation. The workshops and working groups served as the basis for developing an advocacy roadmap and white paper on TVF transportation systems, technology, and markets.

Acknowledgments

Dedication
This white paper is dedicated to Mr. Michael Dudley, whose passion, enthusiasm, and motivation in the Transformative Vertical Flight Working Groups inspired us to pursue the revolution of eVTOL aircraft

NASA TVF WG Sponsor
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Executive Summary

History has shown that our personal life is highly dependent on the technology that people have developed. A strategic scan of the aerospace environment at the beginning of the 21st century strongly suggests that the world might be approaching a new age of airpower—the era of electrified/hybrid aircraft propulsion. Undeniably, starting from the Montgolfier Brothers balloon flight in 1783, to the Wright Brothers piston engine flight in 1903, and the jet engine of the 1960s, or the space age of today, one can say that leaps in propulsion technology have marked the different ages of human flight. The technological advancements, brought at the beginning of 21st century by the revolution in data exchange, computational power, sensors, wireless communication, internet, and autonomy, contributed to the vision of this new age of propulsion we are approaching.

Historically, conventional vertical takeoff and landing (VTOL) aircraft have been equipped with propulsion units relying on complex internal combustion machines (turbines, piston engines, for example), and complex mechanical arrangements (gearboxes, shafts, variable pitch propeller). By contrast, **electric VTOL aircraft (eVTOL)**[1] rely on simpler propulsion units (electric motors and in some cases fixed-pitch propellers). This promotes redundancy and improves tolerance to failures, in turn improving safety. The use of simpler electric propulsion units should also allow significant acquisition and operating cost reductions. Whether full-electric (relying solely on batteries) or hybrid-electric (relying on a combination of batteries, fuel-powered engines, and generators.), eVTOLs are also expected to generate less noise and air pollution than conventional aircraft with similar payloads.

According to the 2019 Annual Review of IATA (International Air Transport Association) [ref.1], due to an expected increase in air transport traffic by 5% every year and a doubling of air transport passenger numbers to 8.2 billion by 2037 significant challenges are posed to the aviation industry. Furthermore, this report does not factor in the expected demand for short-range (intra-city) air transportation, which is in development and yet to be operational. The increased demand to fly creates a responsibility to expand in a sustainable manner and an endeavor to develop more environmentally-friendly aircraft. eVTOL aircraft, either piloted or autonomous, is gathering considerable interest worldwide. Modern and novel full-electric or hybrid-electric eVTOL configurations enable a new paradigm shift in air transportation as the aviation industry remains committed to its goals of carbon-neutral growth from 2020 onwards and cutting CO2 emissions to half 2005 levels by 2050.

While electric power has been used for decades, recent developments in mobile electric/hybrid propulsion coupled with advanced materials and autonomous systems may create the possibility to transition into the next age of air mobility propelled by **electric/hybrid VTOL aircraft technology**. Although eVTOL aircraft might seem like an incremental improvement or even a counterintuitive regression with regard to past VTOL development, it has in fact the potential to transform air mobility across a wide range of government applications. Previous transformations in aviation generated dramatic leaps in performance, but the cost was commensurate with performance, limiting quantity produced. This next age appears to take a different approach. Performance may not increase, but at this moment technology is poised for future urban mobility that will spawn commercial passenger drone services, that is, autonomous (pilotless) air taxis and thereby add a new dimension to the urban transportation mix of the

1 Throughout this document, eVTOL aircraft refers to Vertical Take-Off and Landing aircraft leveraging the benefits of Distributed Electric Propulsion (DEP). It includes electric and hybrid propulsion options.

future [ref. 2]. Advances in electric propulsion, autonomous flight technology, and 5G communication networks will enable this fast new-growing market to become a reality.

It is now time to envision the introduction of electric/hybrid eVTOL aircraft for Public Services[2]. We believe that in the next decades **eVTOL aircraft will have the potential to become an essential tool to Public Service agencies around the world in applications such as firefighting, public safety, search and rescue, disaster relief and law enforcement**. This is due to several major factors.

- **First,** with the increasing popularity of small, unmanned aircraft vehicles (UAVs) or drones, many companies today are focusing on the development of passenger UAVs designed to accommodate up to five passengers or equivalent cargo payload. Many such configurations are electric or hybrid-electric designs with VTOL capabilities. Several of these projects have started a flight test program and many more are expected to be in the experimental and development phase in 2020. Such revolutionary vehicles could be in commercial operations by 2030. These eVTOL systems could be ready for selected Public Services missions even sooner.
- **Second,** although these advanced eVTOL vehicles under development still need access to fuel (hybrid) and/or electric charging capability, they can take off and land from almost anywhere. Therefore, such vehicles, both manned and unmanned can be successfully integrated for the critical missions of the Public Services with extra deployment flexibilities.
- **Third,** advancement in electric propulsion systems in the automotive industry together with NASA's leading efforts in electrification of aircraft propulsion systems, FAA's ongoing active eVTOL certification programs, and EASA's proposed framework for the certification of electric/hybrid small category VTOL aircraft in Europe [ref. 3] will help accelerate industry electric propulsion system development and integration.
- **Finally,** eVTOL vehicles could be deployed for Public Services sooner than air taxi or other commercial applications, since Public Services missions may be more easily approved based on specific mission criteria, localized airworthiness authority for public-use aircraft[3], and are normally operating under centralized airspace management and control by the theater command. Moreover, public perception and acceptance are generally less of a concern when operations save lives and benefit the wider community.

The prioritized introduction of eVTOL aircraft in Public Services is ambitious, but we believe it is achievable in the coming decades if fundamental enablers (people and technologies) are engaged in defining the objectives and needs of these missions. The revolution that is currently taking place in eVTOL aircraft represents an unprecedented opportunity to develop a safer, more affordable, more available and more environmentally friendly future of vertical flight. To ensure that these novel aircraft meet the future expectations of Public Services, it is essential to take a collaborative and multi-disciplinary approach to their development, across engineering disciplines, policy-making, program management, business case development, manufacturing, and flight demonstrations.

It should be noted that the term eVTOL (in the near term) used throughout this publication implies aircraft capable of transporting up to 5 persons which may or may not include a pilot if operated fully autonomously, assuming an average of 200 pounds (91 kg) per person or equivalent payload and a range up to 60 miles plus a suitable reserve. Hybrid or hydrogen powered eVTOLs would have greater range. For example, a "3-seat" eVTOL aircraft may only

[2] Public Services are defined as services performed for the benefit of the public (Merriam Webster dictionary)
[3] "*Public aircraft are exempt from the regulations that apply specifically to civil aircraft*" (see "A Question of Public Use", Vertical Magazine, posted October 12, 2017, https://www.verticalmag.com/features/question-public-use/).

be able to carry two fully equipped firemen, and payload capacity is more relevant when used for the supply mission. Moreover, this paper concentrates on the “last-mile” solutions with a deployment time of no more than 6 hours. Although not specifically discussed in this document, it is understood that the future of Transformative Vertical Flight in general and Public Services, in particular, will also involve smaller UAVs that will undoubtedly play a crucial role in future aerial operations. For example, smaller unmanned aircraft may be used to dispatch medical supplies, portable filtration systems or perform the Search task of future Search and Rescue (SAR) operations.

Close collaboration between the aircraft industry, the Civil Aviation Authorities (CAA), e.g., Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA), Transport Canada Civil Aviation (TCCA) and the Department of Defense (DoD) certifiers, will help identify Public Services requirements, define expectations and limit development cost and timescales. Take the US Air Force Agility Prime as an example, the majority of the eVTOL application opportunities and mission elements identified are in line with the NASA TVF WG-4 objectives and use cases. Together, it forms a strong partnership to accelerate the development, certification, and practical deployment for public service missions.

The US Air Force Agility Prime has been a collaboration partner on this white paper, and provided valuable input and recommendations. Most of the eVTOL public service mission elements discussed in this paper and additional use cases envisioned by the NASA TVF WG-4 team are shared by the Agility Prime program. The focus and efforts of the Agility Prime in product and system development, industry and government partnership, accelerated certifications as well as early test and deployment are totally in sync with the path forward recommended by this white paper. This kind of collaboration and partnership will help enable the practical use of the eVTOL for public service missions, benefit the eVTOL public acceptance, and accelerate the eVTOL industry revolution.

Introduction

Market forces driving aircraft technology and the value for Public Service

The famous quote by America's thirty-fifth president, John F. Kennedy: "Ask not what your country can do for you, ask what you can do for your country" expresses the inspiration for the entire Public Services. The image of Public Services operations is compelling: operating during flooding, earthquakes or fighting wildfires; their ability to be selfless; to be open to the needs and values of others; awaken our sense of humanity and respect. This makes Public Services a pervasive power. The key to enhanced Public Services operations is to possess smart solutions with efficient tools capable of solving the perpetual problems of disaster relief.

Think about the advancements in aircraft technology over the last couple of years—engineers and flight test professionals have successfully prototyped and flown various Electric Vertical Takeoff and Landing (eVTOL) aircraft with shapes that had previously been relegated to science fiction. This freedom to design emerges directly from the availability of reliable brushless direct current (DC) electric motors -known as BLDC motors or BL motors)[4] [ref. 4, 5] controlled by fast, closed-loop electronic feedback controllers and sensors. Those electronic control systems can quickly command speed changes to the motors, which are very responsive. When designed and programmed properly, the controllers can make aircraft fly with stability and precision. The scalability and simplicity of electric motors offer thrust capabilities for alternative modes of maneuverability through distributed electric propulsion.

More than one hundred fifty companies are in the process of developing prototypes [ref. 6] in a fierce competition between startups, including Kitty Hawk (US), Lilium (Germany), Joby Aviation (US), E-Hang (China), Volocopter (Germany), as well as large firms like Airbus (with a special A^3 by Airbus located in Silicon Valley), Boeing (US), Bell (US), Embraer (Brazil), and Uber (US). Additionally, the Big Four technology companies, Amazon, Google, Apple, Facebook (US) known for the disruption of well-established industries through technological innovation are moving into the eVTOL aircraft endeavors, placing vast venture capital and highly-talented human capital into these efforts. Venture capitalists have invested more than one billion dollars into promising eVTOL aircraft startups [ref.5]. Well-known CEOs, billionaires, and politicians are leveraging personal credibility supporting eVTOL projects. For example, Google's co-founder has invested $100 million[5] in a "flying car" concept, and Airbus recently pledged some $150 million of associated R&D. Furthermore, Uber has authored a 98-page white paper describing potential engagement in this new industry and plans to begin initial flight trials in Dallas and Los Angeles by 2020 [ref. 7].

The eVTOL configurations vary from hover bikes to electric ducted fans [ref. 8]. The Uber Elevate white paper released in 2016 "Fast-Forwarding to a Future of On-Demand Urban Air Transportation," [ref. 7] elaborated plans for an on-demand urban air transportation service using thousands of eVTOL aircraft—eventually autonomously piloted—with very low direct operating costs, low noise and zero "tailpipe" emissions.

The development of distribute electric propulsion (DEP) appears to enable cheap, quiet, and reliable short-range VTOL aircraft. Indeed, a substantive operating cost improvement is hypothesized as a result of decreases in the cost of energy for flight propulsion, reduced maintenance hours, and reduced unique part count for eVTOL aircraft [ref. 9]. According to [ref. 3], energy sourced from the electrical grid costs as little as 30% of equivalent energy

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[4] Brushless DC motors are similar to alternating current (AC) motors powered by a 3-phase waveform.
[5] All dollar ($) entries are in United States dollars, unless otherwise stated

delivered from aviation fuel. *"Considering that fuel typically comprises 20% of rotorcraft operating costs, this 3x reduction in energy costs offers the potential for a direct 6% reduction in operating costs for energy alone using pure battery electric configurations"* [Ref. 3], discussing on the direct operating cost (DOC) for future e-aircraft, concluded that not only the battery pack price is important but also the longevity (number of cycles) and the operation profiles (charge/discharge) are also important. For example, going from 5000 cycles to 1000 cycles will reduce DOC by 50%; going from 1.5 cycles per flight hour to 1 cycle per flight hour will also reduce DOC by 50%. The key parameter for battery replacement and DOC depends therefore on the operation and the charge/discharge profile. This is why, with DEP, a new era of transformational vertical flight could commence with flying cars being a "hot ticket" item of late [refs.11, 12]. Since 2010, many researchers, companies, and startups have started to work on eVTOL aircraft solutions. Now, most of the major aircraft companies are directly developing their own eVTOL aircraft or have subsidiaries doing it. Uber, with its Uber Elevate program, is coordinating the development eVTOL aircraft and their operations [ref. 7]. Aircraft manufacturers such as Kitty Hawk (US) have developed and is now testing two vehicles: Cora, the lift cruise air taxi and the Flyer, a hoverbike (see https://kittyhawk.aero). Lilium (Germany) has developed different electric ducted fan eVTOL prototypes, including a two- and a five-seater air taxi (see https://lilium.com/). Joby Aviation (US) has performed tests on electric propulsion and is building an eVTOL prototype (see https://www.jobyaviation.com/). PAL-V (The Netherlands) has developed the world's first flying car production model (see https://www.pal-v.com/). E-Hang (China) has manufactured quadrotor UAVs and has built and tested, with humans on board, the E-Hang 184 passenger drone (see http://www.ehang.com).

There are those who argue that electrifying commercial aviation in the next few decades *"does not seem to hold the potential … for significantly reducing airliner energy consumption nor for supplying that energy at lower net carbon emission nor for reducing energy cost"* [ref.13]. However, the above examples are instances of capital and technology infusion with market perturbations that few would have predicted five years ago and indicate the degree of potential disruption in the aerospace market in the near future. Yet, after years of discussing the opportunities of commercial technologies, it is not clear that the US Federal Government is adequately considering the potential of large-scale eVTOLs for potential logistics cost savings and operational agility.

Concluding, the revolutionary infrastructure currently being built for on-demand urban eVTOL aircraft needs to be considered for the next decades of Public Services operations. For a future safe and efficient air transportation system in Public Services, we need to fully comprehend and predict this urban air transportation of the future. The goal of the present document is to identify scenarios for Public Services in which the eVTOL aircraft transformative revolution can be applied. Each chapter presented in this paper will connect specific Public Services scenarios of firefighting, humanitarian aid, disaster support, medevac, and last mile aerial delivery to eVTOL functionalities. The identified eVTOL capabilities should be robust or versatile enough against potential scenario changes.

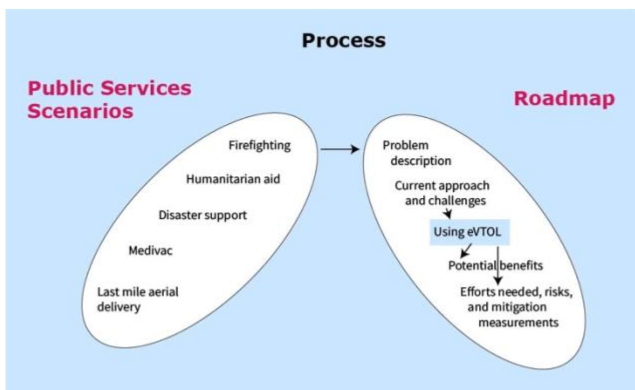


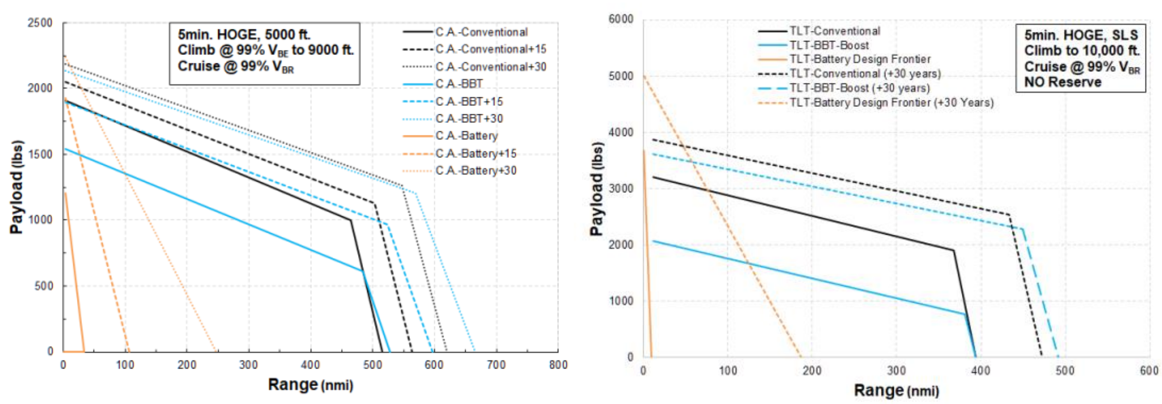
Figure 1. White Paper specific scenarios for eVTOL Public Services and their organization. Diagram courtesy of Marilena Pavel

Technology Specifics

The potential of eVTOL aircraft to transform air mobility across a wide range of government applications needs to be understood in the context of specific technologies to encounter. The main challenge with electric flight in general and eVTOL aircraft in particular remains with the low energy density of batteries (typically, packed Li-Ion batteries have a specific energy of 230–260 Wh/kg at the cell level and 180–200 Wh/kg at 3–6°C discharge rate). Such energy density is significantly lower than hydrocarbon fuels that have stored energy density of the order of 12,000 Wh/kg). This discrepancy in energy density is expected to limit the range of electrically powered aircraft and rotorcraft. Furthermore, batteries approved for commercial aviation use will take a bigger weight hit for thermal management systems and safety features. They also are less than 100% efficient on discharge and typically should not be discharged below 20% state-of-charge.

Typically, a DEP VTOL may have an overall efficiency of ~75% when considering losses in electric motors and controllers, losses during battery discharge, losses in electrical distribution. Comparatively, a conventional hydrocarbon-based helicopter may have an overall efficiency as low as ~25% when considering the losses in small piston engines and the mechanical losses in transmissions, couplings and gearboxes as well as the effect of altitude on performance.

This energy discrepancy is continuously narrowing as existing battery chemistries mature (e.g. ~3–5% improvement per year for Li-ion technology) and new battery types are being developed (for example, solid-state, Li-metal, Li-sulfur) but it is unlikely that battery energy density will allow electric aircraft to compete with fuel-powered aircraft in the near future on range or endurance. As an example, based on current Li-ion battery performance (energy and power density), assuming an efficient convertible design (i.e. winged), an eVTOL aircraft can be expected to achieve ranges on the order of 60 miles while retaining sufficient reserves.



C.A. Conventional = Conventionally powered Configuration A light helicopter with a design TOGW of 5,781 lbs
C.A. BBT = Configuration A–based battery-boosted gas turbine hybrid electric helicopter
C.A-Battery—All-electric, battery-powered variant of Configuration A.
TLT-Conventional—Conventionally powered tiltrotor vehicle calibrated to match the performance of the XV-15.
TLT-BBT-Boost —Hybrid variant of the tiltrotor configuration featuring downsized engines and a boost battery using a parallel hybrid propulsion architecture. The battery is sized to provide sufficient power for boosted hover, boosted climb, and OEI operations.
TLT-Battery Design—All-electric, battery-powered variant of the tiltrotor configuration.

Figure 2. Hybrid electric helicopter and tiltrotor developments in a timeframe of 30 years.
NASA Contractor Report. 2018-219897. Image courtesy of Empirical Systems Aerospace, Inc.

However, the era of electric aircraft propulsion is evolving at an astonishing rate. With the rapid technological advancement in the fields of batteries, electric motors, conductors, lightweight materials, and thermal management, all show that eVTOL aircraft are much closer to reality. A recent study by NASA [ref. 14] showed that "*the improvements to electrical component performance are expected to outpace the improvements to gas turbine technology*," suggesting that within 30 years a conventional light helicopter with battery boosted turbine propulsion will have similar payload capabilities than the baseline vehicle while exhibiting a reduction in fuel burn and subsequent increase in range. For the all-electric battery air vehicle, range will remain limited for the foreseeable future but sufficient for short-range rescue operations. Furthermore, in this study, a hybrid-electric tiltrotor is expected to achieve a 10% reduction in cruise fuel consumption, compared to the traditional NASA XV-15 tiltrotor, and the success of this design effort suggests that "*the design of a manned, hybrid-electric tiltrotor is technically feasible at current technology levels*."

It is important to understand however that eVTOL aircraft are not being developed to compete on range with conventional helicopters, but rather offer an alternative form of air transportation that promises to be versatile (able to take off and land vertically from rudimentary landing zones), economical (reduced acquisition and operating costs), accessible (enabling operators with little to no flight training or experience) and safe (designed to better tolerate failure modes). In this context, range is a lesser priority and missions can be adapted to provide "**last mile**" air support missions with ranges on the order of 25–30 miles being sufficient.

Winged eVTOL aircraft, with a lift to drag ratio (L/D) more than double that of conventional helicopters will be significantly more energy efficient than their hydrocarbon fuel counterparts, reducing the energy required for a given mission, whether derived from renewable energy sources or not. As such, in places with limited access or availability to electricity, eVTOL aircraft may still efficiently be re-charged using diesel generators.

It is also important to understand the unique characteristics of eVTOL technology. The use of DEP has created significant flexibility, potentially allowing new aircraft configurations, architectures and control methods. "Electric propulsion is scale-free in terms of being able to achieve highly similar levels of motor power to weight and efficiency across a dramatic scaling range" [ref. 15] [6] For example, redundant DEP may be used to improve fault tolerance and safety in flight. To implement such level of redundancy using conventional propulsion methods often results in complex, heavy and bulky mechanical arrangements (e.g. shaft couplings, gearboxes, clutches, etc.). The use of electric motors can also improve safety on ground through a reduction in noise, heat dissipation and possible toxic fumes, as well as turning off rotating propellers or rotors before passengers' ingress or egress.

Additionally, although propellers or ducted fans of the DEP still generate noise (level and frequency would depend on the tip speed, disk loading, and other design parameters), and to a lesser extent, BLDC motors has its unique acoustic signature. Through a combination of DEP configuration (multiple smaller rotors with direct electric motor drives), tip speed limitation, the removal of or minimizing engine/turbine/gearing noise sources, and the potential use of fixed wings for efficient forward flight, eVTOLs are anticipated to have a modified and reduced noise signature compared with conventional helicopters of similar size, with a target noise reduction of 15 dB or more. Battery powered eVTOL aircraft also have a reduced environmental impact with zero operational emissions. Note that distributed propulsion enables lower tip speed with less degradation in aircraft performance. Further, using DEP in place of complex shafts, cross couplings and gearing arrangements is expected to reduce both acquisition, maintenance and operating cost. When extended range is needed, aircraft can be designed with hybrid-electric propulsion systems, which can take advantage of operating smaller engines at peak

[6] A word of caution must be mentioned here: at small scale, DEP cannot properly work due to compressor blade clearance issues and throttle response rates.

efficiencies. Running the hybrid power unit engine at idle or off during takeoff and landing can further reduce the noise signature of the aircraft at lower altitude.

Developments in autonomous and semi-autonomous technology also bring the prospect of new capabilities and applications for transporting either personnel or cargo. Remotely piloted or fully autonomous aircraft may allow applications in hazardous situations without putting the life of first responders or pilots at risk. Optionally-piloted aircraft may allow the flexibility of flying with human pilots for highly dynamic scenarios that require human-IN-the-loop reactions, or flying autonomously during preplanned low-altitude, night, or poor weather scenarios where the situation only requires a human-ON-the-loop. Full autonomy provides the capability for mission success when remote communication or navigation cannot be assured or where aircraft sensory systems are superior to human capabilities. For example, zero visibility scenarios such as flying through smoke, dense fog, clouds, etc. is a problem for the human eye, but not necessarily a problem for sensors that can detect other forms of electromagnetic radiation (e.g. infrared).

In general, conventional helicopters and VTOL aircraft in particular offer a reduced logistical burden by being able to operate without a runway and with minimal ground infrastructures, for example, it allows collecting payload in remote locations. Modularity in the design may also provide rapid and agile reconfiguration of the aircraft to respond to a variety of national disasters or logistics challenges without designing complex, do-it-all aircraft, or specific, limited scope variants. Furthermore, cost may be driven down by using commercial-off-the-shelf (COTS) [ref. 16] components and parts when possible, potentially allowing military, interagency and commercial users to employ the same baseline platform. However, COTS is not a panacea for cost reduction if the component is used in critical applications (e.g., Design Assurance Levels A, B or even C) and hence requires typical aircraft quality and reliability to meet safety assurance requirements.

Overall Risk and Mitigation

To realize the full potential of this opportunity, cooperation across the whole of government is critical. All agencies should assess requirements that might be met by these technologies for further economies of scale and operational agility (e.g. disaster relief, firefighting, international development, law enforcement, medevac, etc.). Next, they should engage with industry to evaluate how current policies and regulations could be modified or adapted to foster this new market without compromising public safety so that, based on commercial demand, the high industry production rate can drive costs lower through economies of scale. This technology can be one subset of a new transportation architecture to decrease carbon emissions and strain on existing infrastructure dramatically.

When assessing lessons from developing new design solutions, one often finds failures to: a) define proper requirements; b) account for stakeholder interests; c) understand technical maturity; or d) consider the total life-cycle cost. Regarding eVTOL aircraft, addressing first, the public acceptance is of paramount importance. The NASA Urban Air Mobility (UAM) Market Study in 2018 showed that “consumers distrust autonomous technology and are not aware of safety systems in place” [ref. 17]. The Airbus Urban Traffic Management (UTM) study on Urban Air Mobility public perception in 2019 showed that the main public concerns relate to the safety of the individuals on the ground, the type and the volume of noise generated, the time of day when using UAM, and the altitude at which the aircraft is flying. [ref. 18]. Providing therefore testing and broad public interaction with these technologies in safe spaces[7] is paramount for

[7] This “sandbox” concept has been implemented with the FAA’s Test Sites (https://www.faa.gov/uas/programs_partnerships/test_sites/) AND the UAS Integration Pilot Program (https://www.transportation.gov/connections/unmanned-aircraft-systems-integration-pilot-program-selectees-0).

success. In the same vein of culture, several of these technologies could lead to different concepts of operation and potential organizational restructuring, resource prioritization, and career field repurposing that could challenge established organization cultural norms. It is important to take an incremental approach, stating clearly that this technology could provide a low-cost hedge to current platforms, but it is not intended to replace them. Current resourcing profiles should not change until prototyping, testing, and operations demonstrate the value of this hedging option. If there are overwhelming benefits, there will be a natural pull. Perhaps transformation can occur without the destructive part of creative destruction. Any potential losers in such a transition should be identified early and actively advised.

Second, technological limitations will exist. Electric power storage technology must continue to improve battery energy density and ensure satisfactory performance. It seems highly likely that batteries will continue to develop at a rate where this technology will become highly competitive in less than a decade. In the interim, there are several steps to continue the parallel development of other associated technologies that can still yield near-term advantages. Establishing technologies and concepts of operations for autonomous re-charge/re-fuel logistics to increase range should begin immediately.[8] Another option is to use hybrid power systems until fully electric systems mature. Many of the mid-range operations could be feasible with petroleum-powered hybrid electric power systems or a range extender. Some use cases might require higher-end petroleum-based propulsion systems (light hybrid) to meet the demanding mission requirements. In general, the long-term costs of petroleum propulsion systems would be higher than the all-electric-based systems, but they would still be very viable. In any case, advanced modular VTOL using petroleum or hydrogen powered hybrid systems should be developed in parallel to assess the relative benefits and inform long-term investment decisions. Autonomous refueling technologies and hybrid systems are already in development and could be incorporated to mitigate technological risks and range limitations of all-electric eVTOL. Fundamentally, it is essential to see what missions can be done today with the current technology and begin developing concepts of operations that are commensurate with existing technological maturity.

Additional potential challenges associated with the implementation of distributed propulsion technology refer to [ref. 19]: 1) the civil infrastructure network needed for DEP for the benefit of its citizens and 2) the DEP certification process and its delays. Given that DEP is an entirely new approach, new or modified certification processes are required with likely increase in time required from the CAAs and the military initially. At the outset of this effort, significant coordination is necessary with the FAA to leverage combined DoD and FAA test resources as well as align risk constructs. Additionally, it is imperative to begin establishing infrastructure for operating locations and airspace management. The interagency process is absolutely essential to garnering the full benefits of this approach. That said, while the COTS [ref. 16] approach would be optimal, it is possible that even if federal use cases and commercial schedules do not align advantageously, the program can still harvest vast benefits. Even without COTS adoption, initial estimates show that 100 units per year could be produced at approximately $0.5 to $1.2 million per unit. This production rate is likely achievable with a government-only purchase. While there are undoubtedly a series of hurdles, with the right mitigation efforts, significant value is still possible even if the optimal program is not executed in sequence. With expected commercial use of these vehicles in high volume, it is anticipated that the unit cost will drop significantly within a few years as the commercial market develops worldwide.

[8] The idea of refuelling tactical systems has been a cornerstone of American fighter operations for decades.

CASE 1: Fighting Wildfire

Wildfire appears to be an increasing problem worldwide, due in part to factors including climate change, issues with forest management, aging electrical infrastructure and urbanization. For example, in the United States, according to Environmental Protection Agency (https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires) the extent of area burned by wildfires each year appears to have increased since the 1980s.[9] Furthermore, in the past decade California has experienced record impact in loss of life, acres burned as well as significant critical infrastructure and property damages [ref. 21]. The same is true for Australia: the 2019–2020 fires have sent smoke rising high into the atmosphere and travelling around the world. Satellites have detected aerosols and other smoky pollutants crossing the Pacific and moving over the South Atlantic Ocean (NASA Earth Observatory, Aussie Smoke Plumes Crossing Oceans, see https://earthobservatory.nasa.gov/images/145898/aussie-smoke-plumes-crossing-oceans) Primary challenges for fighting wildfire include the need for timely response, insertion of trained fire officers into difficult access areas, safe up-close surveillance in inaccessible or excessively dangerous areas, and maintaining sufficient weight of attack and coordinated action to contain, delay or suppress the fire while also being able to evacuate firefighters and civilians when needed.

eVTOL aircraft may be able to introduce a cost-effective short-range aerial transportation system in wildfire fighting by enabling more rapid and thereby effective firefighting with the potential attendant reduction in firefighter and civilian casualties. This application requires careful integration with full consideration of air vehicle stability in powerful swirling updrafts including so-called "*firenados*" as well as protection of air vehicle systems such as the battery packs in high temperature operations.

A pilot program to introduce the eVTOL capabilities into the firefighting missions could lead to effective development of the best-use methodology, short-term cost, and life-saving benefits while generating high levels of positive public acceptance for eVTOL aircraft, leading to much more public applications.

1) Problem Description

Fighting wildfires can become deadly. A wildfire's front may also change direction unexpectedly and jump across fire breaks. Intense heat and smoke can lead to disorientation and loss of situational awareness of fire direction and intensity.

Firefighters face life-threatening hazards including thermal injury, heat stress, fatigue, smoke and dust, as well as the risk of other injuries such as cuts and scrapes, animal bites, and even rhabdomyolysis [ref. 20]. For example, between 2000 and 2016, more than 350 wildland firefighters died on duty in the United States [ref. 22].

Figure 3. A wildfire burning in Los Padres National Forest, California, 2017. Image: Pixabay

[9] Note that The Great Fire of 1910 (also commonly referred to as the Big Blowup, the Big Burn, or the Devil's Broom fire) was the largest wildfire in US history: it burned through 3 million acres in northern Idaho and western Montana. According to the Forest History Society, the wildfire killed 87 people (2 more than the Camp Fire), mostly firefighters (see http://www.1910fire.com/)

Wildfires have a rapid forward rate of spread (FROS) when burning through dense, uninterrupted fuel [ref. 23]. They can move as fast as 6.7 mph in forests and 14 mph in grasslands, and much faster when driven by strong winds. They may also spread by jumping or spotting as winds and vertical convection columns carry firebrands (hot wood embers) and other burning materials through the air over roads, rivers, and other barriers. Hence the ability to rapidly respond to changing conditions and provide agile response services are a must.

Wildfires are causing significant casualties in addition to property loses and economic impact. In California 2018, 98 civilians and 6 firefighters were killed. In addition, a total of 1.89 million acres were burned costing more than $3.5 billion.

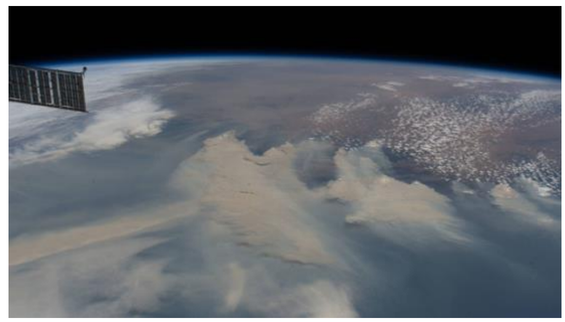


Figure 4. Australia's bushfire season in 2019. Bushfire smoke as seen from the International Space Station. NASA Image

Likewise, Australia has seen many terrible fire seasons. In 2003, fires swept through the suburbs of Canberra, the nation's capital, killing four people and destroying hundreds of homes. In 2009, bushfires in the state of Victoria killed 173 people in a single day—the worst bushfire disaster in Australian history, now referred to simply as Black Saturday. "*In the years between 1967 and 2013, major Australian bushfires have resulted in over 8000 injuries and 433 fatalities, close to 50 per cent of all deaths from major Australian natural disasters in the period (excluding heatwaves). Over this same period, bushfires cost approximately A$4.7 billion (2013 Australian dollars, including deaths and injuries but excluding most indirect losses).*" (https://www.ga.gov.au/scientific-topics/community-safety/bushfire). The recent 2019–2020 bushfire season has shocked Australians through its massive scale. Over 3,000 firefighters, thousands of personnel from the Australian Defense Force, government, non-government and volunteer agencies together with specialists from New Zealand, United States and Canada have been battling over 200 hundred fires, many of them extensive, uncontained and out of control. The fire conditions today are fundamentally different, and fundamentally worse in many ways, when compared with some of the fires experienced in the past. Also, fires are becoming more and more savage, and they are more frequent. In Australia for example, they used to happen every 30 or 50 years, now they seem to be happening by the decade (https://www.news.com.au/technology/environment/how-the-2019-australian-bushfire-season-compares-to-other-fire-disasters/news-story/)

The timeliness and effectiveness in fighting wildfires could be significantly enhanced by more on-demand rapidly deployable air mobility capabilities, while the mass capabilities of transporting and evacuating civilians out of harm's way are lacking based on current equipment and operations.

2) The Current Approach and Challenges

Across the United States, wildfire suppression is administered by land management agencies including the US Forest Service, Bureau of Land Management, US Fish and Wildlife Service, National Park Service, the Bureau of Reclamation, the Army Corps of Engineers, and state departments of forestry. All of these groups contribute to the National Wildfire Coordinating Group and the National Interagency Fire Center.

Firefighters may only suppress fire that has become uncontrollable. All fire suppression activities are based from an anchor point (such as lake, rockslide, road or other natural or artificial fire break). From an anchor point, firefighters work to contain a wildland fire while guarding against the fire outflanking them. Large fires often become extended campaigns. Incident command posts (ICPs) and other temporary fire camps are constructed to provide food, showers, and rest to fire crews. From direct attack, indirect attack and mop-up phases of firefighting, transportation and delivery capabilities on the ground and in the air are critical to the effectiveness and results.

Furthermore, a key technological challenge of civilian evacuation is the need to process extremely large amounts of complex and geographically distributed sources of data. This is where the concept of Big Data can play a role. The term Big Data describes structured, semi-structured and unstructured data, of any volume, that have the potential to be converted into useful information [ref. 28]. In this sense, the creation of a Geographic Information System (GIS) database revealing deeper insights into newer smart systems patterns, relationships, and situations will help making smarter decisions on the distribution of eVTOLs in emergency situations.

Figure 5. Air-Crane helicopter and DC-10 air tanker fighting wildfire in Santa Paula, California, November 2019. Images courtesy of Johnny Doo

Aerial Fire Suppression Methods:

Fire retardants and water can be dropped onto fires by unmanned aerial vehicles, planes, and helicopters [ref. 24]. Complete fire suppression is no longer an expectation, but the majority of wildfires are often extinguished before they grow out of control. While more than 99% of the 10,000 new wildfires each year are contained, uncontained wildfires under extreme weather conditions are difficult to suppress without a change in the weather. Wildfires in Canada and the US burn an average of 13,000,000 acres per year.

Figure 6. Orange County Fire Authority helicopter, May 14, 2014. Image courtesy of Dr. Mark DeAngelo, SAE International

Average US suppression costs are $4 billion to $4.5 billion annually. In California, the US Forest Service spends about $200 million per year to suppress 98% of wildfires and up to $1 billion to suppress the other 2% of fires that escape initial attack and become large [ref. 25]. The US Forest Service (USFS) contracts heavy air tankers, and three companies were awarded contracts. Now they maintain a combined fleet of 23 aircraft (see more information on the US Forest Service internet site https://www.fs.fed.us/).

Firefighter deployment and extraction methods:

***Hand Crews*.** Typically, wildland firefighting organizations will use large hand crews of 20 or more people who travel in vehicles to the fire incident.

Smoke Jumpers. Highly skilled firefighters specially trained in wildfire suppression tactics. They parachute into remote areas from aircraft to combat wildfires and are equipped to work in remote areas for extended periods of time with little logistical support.

Figure 7. A smoke jumper parachutes to a wildfire. Image: US Forest Service

Helitack. The use of helicopter-delivered fire resources varies by agency. Often, helitack crews perform duties similar to other initial attack crews. Two or three firefighters will be dispatched to a newly reported fire. Helitack crews are usually used for initial attack on fires that are difficult for other firefighters to access, or on extended fires that require aerial support in the form of water drops, cargo delivery, crew shuttling, or reconnaissance. A typical initial attack response by a helitack crew involves flying to the fire via helicopter and spending one to three days (although sometimes much longer) putting the fire out before hiking to the nearest road for pickup.

Figure 8. A rappeller firefighter descent from the helicopter. Image: US Forest Service

Rappeller. A highly effective way to fight wilderness fire when no roads are nearby is to have wildland firefighters rappel from a helicopter. These firefighters then take suppressive action on the fire or clear a safe landing zone to receive additional firefighters if the fire is too large. Rappellers usually carry 30 pounds of personal gear plus up to 300 pounds of fire gear which is lowered down to them from their helicopter. Rappelling heights can range from 30 feet (in tall, continuous brush) to 250 feet (in timber). When suppression is complete on rappeller-responded fires, ground transport is typically arranged to pick up the firefighters at the nearest road. These crews carry chainsaws, hand tools, radios, and can even have 75-US-gallon (280 L) water bags, known as blivets, flown in to help fight the fire.

Fires at the wildland-urban interface and evacuation requirement

There are three categories of interface fire: the classic wildland/urban interface exists where well-defined urban and suburban development presses up against open expanses of wildland areas; the mixed wildland/urban interface is characterized by isolated homes, subdivisions and small communities situated predominantly in wildland settings; and the occluded wildland/urban interface exists where islands of wildland vegetation occur inside a largely urbanized area [ref. 26].

Urbanization and other human activity in areas adjacent to wildlands is a primary reason for the catastrophic structural losses, and casualties experienced in wildfires [ref. 27]. Fuel buildup can result in costly, devastating fires as more new houses and ranches are built adjacent to wilderness areas. As a result, more timely and effective wildfire evacuation is needed beyond the current approach that has been managed by local city and regional government agencies relying mostly on existing roadways. Some properties are undefendable by traditional firefighting responses because of their location in wildland vegetation areas.

The transformative technology of eVTOL aircraft enables the potential of saving what is now undefendable through surgical rapid insertion of fire crews and/or evacuation of civilians. Further, using firefighting eVTOL aircraft at the wildland-urban interface focuses the strength of eVTOL operations for rapid and repetitive response rather than long-range flight ops.

Current System Shortcomings:

Aerial firefighting vehicle types and costs:

- Situational awareness, communications, and actionable intelligence sources have been improved recently using unmanned aircraft (UA), but fire suppressant and water delivery methods remain reliant on traditional fixed-wing air tankers and helicopters. While aerial response with large air tankers and helicopters are a critical part in fighting wildfire, the limited number of these air vehicles and high costs associated with their operations sometimes limits on-demand responsiveness.

Fire crew deployment and extraction:

- **Hand crews** often deploy by ground vehicle but can be limited by the distance from roadway to the fire site. This can cause unnecessary delay and fatigue due to the excessive travel distance over difficult terrain while manually transporting heavy equipment.
- **Smoke jumpers** parachute into remote areas with limited logistical support, extraction can be time-consuming and difficult.
- **Helitack crew** involves flying to the fire via helicopter and spending one to three days putting the fire out before hiking to the nearest road for pickup. This is the same with rappellers when suppression is complete, ground transport is typically arranged to pick up the firefighters at the nearest road [10]. Means of extraction could be improved to reduce workload and enable more timely return to the base camp.
- The ability for extraction and evacuation of fire crews when fire changes directions or intensities, is sometimes limited by the transportation platforms we have available today. VTOL and eVTOL operations in and around wildland fires incur elevated risk due to low visibility and fire turbulence (i.e., “firenado”).

Figure 9. Firefighters in the fight against forest fires. Image: Commons Wikimedia

Figure 10. Massive bushfire in Australia. Image: Pixabay

Civilian evacuation depends on the available ground and air vehicles, often limited in timelines and effectiveness.

- **Ground vehicle**. Major challenges when roadways are congested with fire equipment or evacuees or if blocked by fire.
- **Air vehicle.** Often rely on helicopters when available, but often limited in effectiveness by available landing locations, distance from the landing site to people, and atmospheric conditions of available helicopters.

[10] Wikipedia - Wildfire suppression equipment and personnel, 2019-02-19

3) Using eVTOL Aircraft

eVTOL aircraft can significantly contribute to wildfire response in three key missions:

a) Fire Suppressant Delivery

By incorporating the vertical takeoff from many more locations than traditional airports, eVTOL aircraft could deliver fire retardant on demand and in a more timely than current methods – rapid suppression can prevent many wildfires from becoming uncontained and uncontrollable. The carrying capabilities of eVTOL aircraft make it ideal for surgical delivery of medium to small quantities of fire retardant during the incipient stage of the fire. The autonomous flight capabilities of eVTOL aircraft allow it to be customized for such missions effectively eliminating pilot risk during the mission. Autonomous flight is most appropriate for missions deemed dull, dirty, and dangerous. Furthermore, a swarm of unmanned aircraft can attack the fire collectively or teams of aircraft can rotate flights and recharge cycles for continuous firefighting.

Figure 11. By combining Compressed Air Foam (CAF) and other extinguishing mediums, a small eVTOL like the one from Esprit can become an effective firefighter. Image courtesy of Esprit

b) Firefighter transportation

The ability to quickly transport firefighters with their equipment to the required location without exertion is another critical capability. More importantly, they can be evacuated quickly if fire changes direction and/or intensity. Working in conjunction with ground transportation, eVTOL aircraft can be used for short-range extraction of smoke jumpers back to roads to rendezvous with ground evacuation. These capabilities alone offer efficiency the opportunity to protect firefighters' lives.

c) Civilian Evacuation

eVTOL aircraft can save civilian lives. In California in 2018, many citizens lost their lives because fire quickly spread toward residential areas, and road congestion during evacuation prevented some civilians from escaping. eVTOL aircraft can be deployed quickly and into schoolyards, shopping mall parking lots, etc. to effectively transport people away from hazards. It may take many years before the general use of eVTOL aircraft is available in sufficient quantity and distribution for these missions to be effective, but it deployment can be expected as the industry and technology matures.

Figure 12. General purpose eVTOL can be useful for personnel transport and evacuation on demand during emergencies. Image courtesy of Johnny Doo

The eVTOL system would not be operating independently, rather it will be integrated into the overall incident command and control (C2) integrated with ground operations, unmanned aircraft systems (UASs), helicopters and aerial tankers to form a cohesive, effective and safer integrated capability.

Small unmanned aircraft system (sUAS) may also be used to provide persistent surveillance so that firefighting activities can be coordinated effectively to manage fire containment. This approach would be enabled by integrating low-cost eVTOL units for deployment in a distributed manner by the firefighters to provide local and rapid on-call fire suppression service. In more rural areas this service might also include response to structure fire.

4) Potential Benefits

By adding short-range on-demand air mobility systems to wildfire fighting efforts, mission effectiveness is enhanced (for example, one may need to have a fleet of 3–4 eVTOLs for every 20–50 miles radius). More importantly, we can reduce risk to firefighters and civilians.

- **Early surgical suppression** – preventing fire from becoming larger or uncontrollable requiring enormous expenditure of effort and resources to overcome, with attendant high risk to people and property. One recent solution for quickly locating wildfires around the globe is NASA's FireSat concept, a constellation of more than 200 thermal infrared space-based imaging sensors mounted on satellites and designed to quickly locate wildfires around the globe. "*While existing satellite-based fire-searching sensors can only detect fires about twice a day, and transmit large images, FireSat would be able to send a low-resolution image of a fire once per minute, along with the latitude and longitude of exactly what is burning. This would enable faster, nearly continuous communication with the ground*." [ref. 29]
- **Safer and more effective firefighter operations** –Deliver firefighters to the target location in a much timelier manner without them becoming exhausted when reaching the incident location. Transport firefighters back to staging areas from fire sites (and more importantly, autonomously extract them from locations when a fire changes direction) thereby exposing them to immediate danger. That would be a significant lifesaving function of eVTOL aircraft.
- **Reduce civilian casualties** – Providing on-demand air transportation to evacuate civilians in a critical situation can significantly reduce potential fatalities especially when a fire changes direction and tracks toward unprotected subdivisions or neighborhoods with roadways that are either congested or blocked by fire.
- **Financial –** reducing the percentage and severity of wildfires to limit the destruction of millions of acres of land and thousands of structures can result in billions of dollars of financial savings when the system is fully implemented.
- **Public recognition and goodwill –** by proactively dealing with wildfire challenges, the public will recognize the efforts put forth by government agencies and the regional/local organizations in their behalf.
- **eVTOL industry growth** – the goodwill generated by these types of Public Services applications can pave the way for public acceptance of eVTOL aircraft, further enhancing the industry growth by creating additional market and applications beyond air taxi operations. The expansion of the eVTOL ecosystem industry can generate additional tax revenue as well as build a new US-leading industry with long term growth potential.

5) Efforts Needed, Risks, and Mitigation Measures

Efforts

Plan and fund a pilot program to demonstrate and evaluate the effectiveness of using eVTOL systems to aid wildfire fighting efforts. Requires partnership and funding for government agencies and commercial companies to develop mission-tailored vehicles and systems.

Tasks and Timeline

There are many approaches we can take to enable the progress leveraging eVTOL system for fighting wildfire; the phased path forward tasks could include the following:

- Planning and assessment
- Funding plan and solicitation OEMs to support the pilot program
- Establish partnership in the vehicles, operations, and logistic
- Prototype vehicle and system testing and demonstration
- Mission specific vehicle modification and development
- Pilot deployment and trial operations
- Expand operating envelops and missions (in line with wildfire season)

The actual timeline would depend on the industry progress, certification for specific missions and public-use approvals, and end-users/government agencies' collaboration. Since most of the operations are over wildland for fighting wildfire, the fire suppression and logistic missions with reasonably low risks to the people on the ground can be implemented earlier. Firefighter transport and civilian evacuation missions will have to follow with demonstrated reliability and operating experiences. It is envisioned that a phased implementation to match the maturity level of vehicle and system would allow practical and successful deployments. Based on the industry progress to date, initial unmanned trial missions could start as early as 2022-2023, while manned missions may start in the 2023-2025 timeframe.

Risks and Risk Mitigation

- **Technology integration and reliability**. eVTOL operations will likely be restricted by the regulator to Part 107, or Part 107-like operations, i.e., line of sight, monitored NON-AUTONOMOUS operations for surveillance, retardant dispersal, and equipment delivery. Once these operations have demonstrated sufficiently high reliability and safety, then BVLOS monitored operations may be commenced with the Regulator’s approval. Ultimately, full autonomous operations may be approved. It is expected that Regulator (and other GO’s and NGO’s) will require pilot operation of eVTOL systems intended for human transport. That may then proceed to pilot-monitored semi-autonomous operations, and then ultimately to truly autonomous operation for some managed human transport.
- **UAS development and testing**. For UAS developers, UAVs will be based on their current systems but tailored for the above-mentioned missions. The eVTOL system safety assessment and redundancies built into the UAV will be unchanged, a slight reduction of payload could further enhance operational safety. By reducing payload, we can increase the power/lift to weight ratio, resulting in additional controllability especially flying in a fire-induced turbulence and complex terrain.
- **Inter-agency coordination and operations**. This is a new capability that did not exist in the past. It will take close coordination between OEMs, agencies and local community cooperation to make it work as intended. Risks can be mitigated by careful planning,

pre-deployment communications, training and education of the new system capabilities, and understanding the limitations and operations before actual deployment. The selection of missions and locations is critical to ensure success.

CASE 2: Logistics of Natural Disasters and Humanitarian Crisis

According to the UN's disaster-monitoring system, "America sits alongside China and India in suffering the greatest number of natural disasters globally between 1995 and 2015" [ref. 30]. These include earthquakes, storms, floods, and heatwaves, all of which are affecting thousands of peoples' lives and prompting the declaration of a national emergencies.

The frequency of these disasters is only increasing; since 1970 the number of disasters worldwide has more than quadrupled, [ref. 31] and countries are suffering in terms of economic and human losses. Although generally, the number of human lives lost has reduced, recent disasters can defy statistics in cases like 2004 and 2010 and therefore indicates that disasters are becoming more complex, [ref. 32] so we will need new and innovative solutions to respond effectively to them.

In Japan, the year 2018 was declared "year of disaster:" Floodwaters swept across the country in July, killing nearly 200 people and causing the evacuation of close to nine million people. The same month at least 65 people died in a heatwave that saw more than 22,000 people hospitalized. Typhoon Jebi lashed western Japan and was the strongest typhoon to hit the country in 25 years. The northern island of Hokkaido was hit with a magnitude 6.7 earthquake, which triggered landslides. Damages produced by these events led to a shrinking of Japan's economy by 1.2% in the third quarter of 2018 [ref. 33]. Elsewhere in the world, disasters are striking with intensity: earthquakes in Indonesia, the volcanic eruption in Guatemala and deadly wildfires in California in the last few years, all demonstrated how rapidly natural disasters could become critical incidents with significant casualties.

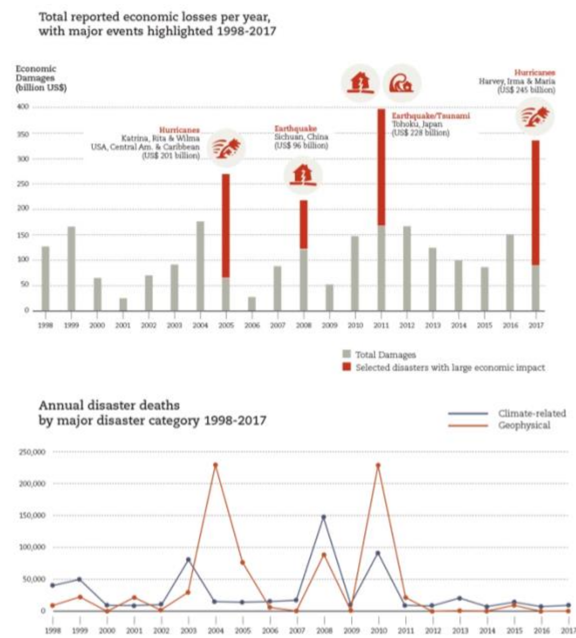


Figure 13. Annual disaster deaths and economic damages. Figures courtesy of The Centre for Research on the Epidemiology of Disasters CRDD, UN Office for Disaster Risk Reduction UNISDR, "Economic losses, poverty and disasters 1998-2017"

In North America the 2017 Hurricane Season was a devastating experience for millions, with more disaster survivors registering for assistance than the previous 10 years combined. The Nation responded to three major hurricanes in quick succession: Harvey, Irma, and Maria. Not surprisingly, the unprecedented scale and rapid succession of these disasters stretched response and recovery capabilities at all levels of government and is transforming the way emergency managers prepare for and respond to disaster events of this scale. The challenges faced required that we innovate and deliver our programs differently.

FEMA Urban Search and Rescue Task Forces, comprised of state and local emergency responders, saved or assisted nearly 9,500 lives across the three hurricanes. These numbers stand in addition to the thousands of lives saved or assisted by DoD, the US Coast Guard, state and local first responders, and neighbors helping neighbors.

Figure 14. Florida slammed by Hurricane Michael, 2018. NASA image

FEMA's 2018–2022 Strategic Plan builds on the lessons from 2017 and an intensive stakeholder engagement process to point the way forward for this Agency and the emergency management community. First, we must build a national culture of preparedness. Second, we must prepare the Nation for catastrophic disasters. Third, we must reduce the complexity of FEMA, making the Agency's programs and services easier and more efficient.

The 2018 Atlantic hurricane season was the third in a consecutive series of above-average and damaging Atlantic hurricane seasons, featuring 15 named storms, 8 hurricanes, and 2 major hurricanes, which caused a total of over $50 billion (2018 USD) in damages (of which, Michael tropical storm was the strongest reaching 155 mph and 57 deaths had been attributed to the storm in the US, see https://en.wikipedia.org/wiki/2018_Atlantic_hurricane_season.

In addition to natural disasters, food scarcity, famines, armed conflict, and terrorist threats, as well as ravaging disease have been some of the biggest triggers that left an estimated 164 million people in 47 countries in need of international humanitarian assistance in 2016, according to finding from the independent organization, Development Initiatives [ref. 34].

Figure 15. Marines attach a barrier to a V-22 Osprey tilt-rotor aircraft. Image: US Army

eVTOL development is quickly becoming a breakthrough industry with promising cost-effective short-range aerial transportation capabilities. A pilot program to introduce the eVTOL capabilities into the national or international natural disaster support missions or humanitarian crisis relief could help save lives, reduce the cost of operations, while improving the public perception of eVTOL aircraft and paving the way for their use in air taxi and other Public Services applications.

1) Problem Description

In the disaster research literature, the response phase is identified as the most critical of three key phases (prevention, response, recovery) [ref. 35]. During this response phase, emergency services are often initially overwhelmed particularly those services located in the area affected by or immediately near the disaster zone. The number of incidents and requests for assistance is often beyond the capacity of command centers and incident management teams to respond to. Damage to critical infrastructures, in particular communications systems, restricts information gathering and other essential elements of a response from occurring in a timely and coordinated manner.

Figure 16. Houston flooding after Hurricane Harvey, August 2017. Image courtesy of Johnny Doo

During this initial phase the need for rapid damage assessment and gathering of actionable intelligence – understanding the size and scope of the problem – is of primary importance. In the immediate aftermath of a disaster, the transportation of relief material with all its challenges is a critical process that it takes place immediately after the disaster.

One of the challenges in any disaster or humanitarian relief effort is the last mile short-range transport capabilities for the distribution of medical aid, personnel, equipment and medicines to affected locations, as well as the evacuation of casualties to medical centers.

For example, FEMA assumed a more active role in coordinating whole community logistics operations for Puerto Rico and the US Virgin Islands due to these territories' preparedness challenges, geographic distance, and pre-existing, on-the-ground conditions [ref. 36]. It provided logistical coordination to move and distribute commodities from staging areas to survivors in Puerto Rico, supplementing a role that should largely be managed and coordinated at the state or territory level.

Scaling a Response for Concurrent Complex Incidents (RCCI), FEMA had to employ all available capacity in the most effective manner possible and reallocate resources for newly emerging requirements (e.g., in 2017 from Harvey to Irma, then to Maria, and finally to the California Wildfires).

Some of the key recommendations from FEMA 2017 review are:

- Promote federally supported, state-managed, locally executed logistics operations
- Broaden FEMA's capability to quickly get teams on the ground to stage and deliver key commodities to disaster survivors, even in the most remote locations

Figure 17. Delivering aid following Hurricane Maria, Utuado, Puerto Rico, 2017. Image: US Air Force

Timely delivery of commodities and medical supplies directly to the survivors—not just to the staging areas—is critical in these national disaster situations. Transportation of the supplies and medical evacuation is impeded by blocked roadways.

2) The Current Approach and Challenges

Traditional ground/sea/air logistical operations rely on transport aircraft delivering supplies to nearby airports, vessels/yachts delivering supplies to harbors (see for example http://yachtaidglobal.org/) and ground vehicles/helicopters delivering goods to survivors. But in many situations after major disasters like hurricanes, earthquakes or wildfires, the roadways are damaged, flooded or blocked by landslides, downed trees, and debris.

Helicopters may be used to drop life rafts, medical supplies, water (or water purification systems), survival kits, and food rations over uneven terrain or confined landing sites. Indeed, the ability of helicopters to hover, takeoff and land vertically to and their external and internal cargo carrying capabilities confers to helicopters a crucial role in disaster relief.

Furthermore, transport of injured people in need of medical care out of conflicted, heavily damaged or flooded areas can pose significant challenges. The ability to have a cost-effective air vehicle capable of taking off or landing at small or unprepared sites bypassing blocked roadways is limited based on today's inventory of transport aircraft and helicopters. Helicopters, therefore, serve critical functions in emergencies, but the number of platforms needed in mass-scale natural disasters or humanitarian crises can overwhelm existing assets.

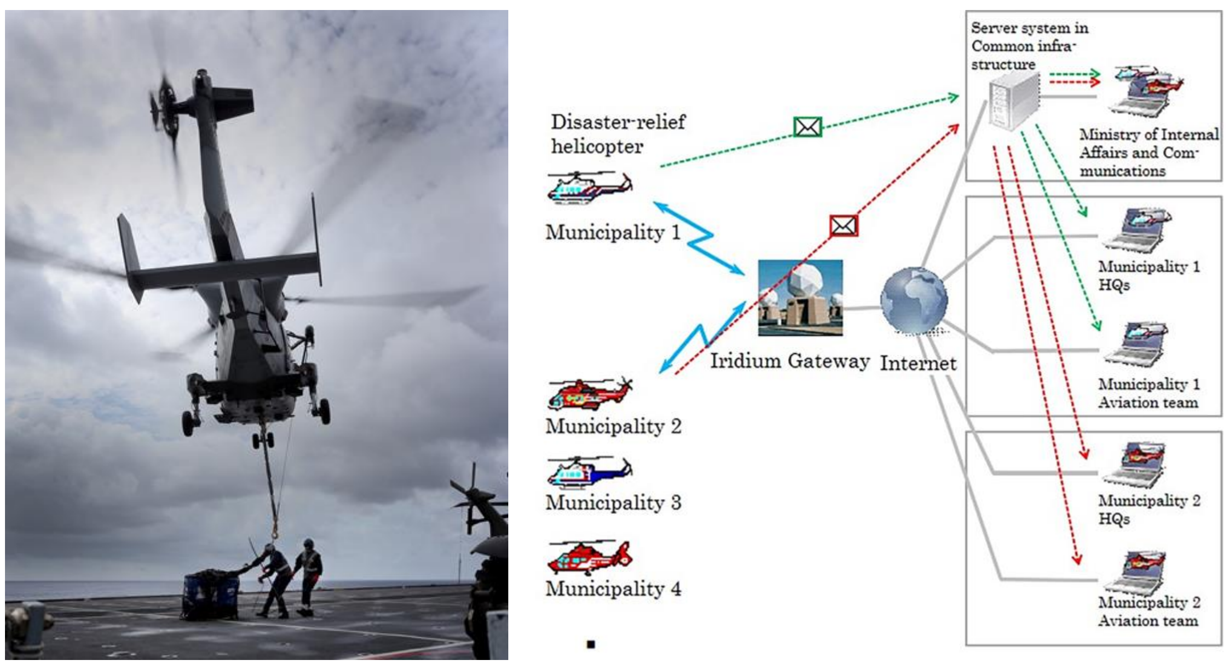


Figure 18. Helicopters used for "Last Mile Distribution and Pickup" function during disaster relief, and JAXA's centralized management system for firefighting and disaster relief, Japan 2014. Left image, Wikimedia Commons; Right image, courtesy of JAXA

When large-scale disasters such as earthquakes occur, a number of helicopters may be flown from neighboring countries/regions/states to assist in disaster relief. The following figure illustrates the JAXA's management [ref. 37] system used to coordinate helicopter operation in such circumstances:

Some charities also specialize in facilitating the use of civilian aircraft/rotorcraft during disaster relief such as PALS (Patient Air Lift Services) or ASF (Aviation Sans Frontières), allowing volunteer civilian pilots to utilize their skills and time in service to the public.

Volunteer and professional helicopter pilots are however in short supply due to the specialized skills and qualifications required to fly these machines. This may limit the full utilization of these rescue helicopters, especially during treacherous operations. The prospect of automated or even autonomous eVTOL aircraft may help resolve the scarcity of skilled helicopter pilots by allowing UAS operators with limited training (relative to a helicopter pilot) to safely operate eVTOL aircraft during emergencies.

Helicopters can be costly to operate which may limit their use and availability. A typical 4–6 seat helicopter's operating cost may range from $500 to $1,000 per flight hour (including pilot cost) while a heavy-lift helicopter may cost $3,000 per flight hour or more. By contrast, the operating cost of a typical 4-seat eVTOL aircraft is expected to be on the order of $300 per flight hour for a full-electric version up to $400 for a hybrid-electric version, including pilot cost, energy cost and battery replacement.

3) Using eVTOL Aircraft

At this point in aviation history, the industry is more aware of the impact of aviation on the environment. With an expected increase in air transport traffic of 5% every year, the efforts to reduce emissions are ongoing. The concept of eVTOL aircraft, with or without a pilot on board, is gathering considerable interest worldwide. This includes a total investment exceeding $1 billion involving major players such as Airbus, Boeing, Bell, Embraer, Intel, Amazon, Honda, Toyota, and Uber [ref. **Error! Reference source not found.**] as well as many smaller c ompanies such as Lilium, Volocopter, Neoptera Aero and Joby Aviation.

A cost-effective eVTOL system can offer complimentary air mobility in several areas:

a) **Commodity and medical supply delivery**
Positioning eVTOL units at the staging area can allow short-range delivery of food, water, blankets, and medical kits to the survivors directly, making a significant impact on the ground situation especially in the first few hours or days of a disaster. The ability to operate from small sites offers much better direct access to the survivors in need of help. The ability to operate in a semi-autonomous manner further enhances the potential to deliver critical supplies without a large number of skilled pilots.

b) **Support team transportation**
The ability of transport support teams, Air National Guard, military and medical personnel into the disaster area and land near the injured persons support work with the most urgent needs can save lives and help people in a timelier manner. Ultimately the eVTOL aircraft can operate remotely with semi-autonomous capabilities to assist in such operations.

Figure 19. The CityAirbus all-electric, four-seat multicopter vehicle full-scale demonstrator conducted its first takeoff in May, 2019. Image courtesy of Airbus

c) **Medical evacuation**
Some eVTOLs can be configured to transport injured persons to the staging area for medical care. It is also feasible to design eVTOL

aircraft to deliver supplies and extract patients on the return trip thus maximizing the utility and effectiveness of the system.

d) Civilian evacuations

When air taxi operations are operating in most cities, they can be redeployed on demand to support large scale civilian evacuations when it becomes necessary.

The eVTOL system will not be operating alone in disaster response, rather they will be integrated into the overall incident command and control in the disaster area working in synergy with the existing ground operations, UAVs, helicopters, and transport aircraft to form a cohesive, effective and safer integrated capability.

Some of the perceived eVTOL aircraft benefits are:

- Affordability: eVTOL aircraft are expected to be more affordable than helicopters with similar levels of safety and significantly lower acquisition costs.
- Operational reliability: The additional level of redundancy required to meet regulatory safety requirements should improve operational reliability for continued safe flight and landing.
- Quieter and user friendly. eVTOL aircraft are expected to generate less noise and air pollution. Furthermore, the rotors or propellers can be easily turned off in the presence of ground personnel. They may also reduce the risks associated with fuel vapor fire hazards and hot exhaust gases. Quieter aircraft, especially when fully electric, would also help with public acceptance of round-the-clock operations.
- Energy efficiency. Winged eVTOL aircraft are more energy efficient in horizontal cruise than conventional helicopters. Efficiency gains may be realized even if fossil fuel is used to produce electricity (however this is not true for some wingless eVTOL aircraft, which can be significantly less energy efficient than helicopters).

The important requirements for a SAR rotorcraft operation during disaster relief include all-weather capability, speed, payload and range. As the needs of high-altitude flight capability and extended hover performance are not necessarily crucial for a rescue helicopter in disaster relief missions, it follows that we can design the eVTOL aircraft to become deployable for short-range disaster relief and aid in future response operations. The use of eVTOL aircraft for operating in "the last mile distribution and pick up" should be thoroughly assessed.

A typical last-mile distribution example is the case of water and food supplies to isolated victims. During flooding or earthquake, as evidenced recently in Indonesia [ref. 39], roads can be destroyed or submerged. The risk of landslides further complicates access by land resulting in isolation of parts of the population. Air access can be crucial in such instances to distribute water and food. According to the Sphere Project [ref. 40] a minimum of 2.5 liters of water is required daily to meet the basic water intake requirements of a survivor plus up to 7.5 liters per day to cover basic hygiene and cooking needs. With many eVTOL aircraft designs capable of transporting up to 4 passengers or 400 kg payload, a single eVTOL flight may meet the daily water needs of up to 160 survivors preventing dehydration and the spread of diseases.

Similarly, the World Health Organization (WHO) [ref. 41] also estimates that 3 to 4 kg per week of food is sufficient to meet the nutritional needs of victims of disasters, suggesting that a 400 kg payload eVTOL aircraft could in a single flight provide the weekly food requirements of up to 130 survivors.

An example of Logistics Support

eVTOL aircraft will only be able to assist in disaster relief operations if they are available as, when and where required. Natural disasters may occur anywhere around the world and in places with limited availability of airplanes and rotorcraft. In many situations, the ability to dispatch eVTOL aircraft anywhere across the globe as quickly as possible is essential. eVTOL aircraft may have to be transported by road, sea or air across significant distances and should therefore be designed to be partially disassembled and reassembled easily, as is often the case with helicopters. For example, the eOpter developed by Neoptera Aero [ref. 42] is a 2–5 seat eVTOL aircraft with wings that can be quickly detached and loaded, together with its fuselage inside of a 20 ft. container.

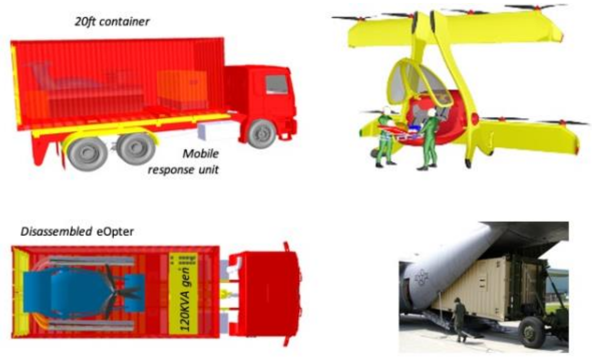


Figure 20. Up to two eOpter, by Neoptera Aero being transported in a 20 ft. container by road or by air to disaster zones. Two Left and Upper Right images courtesy of Neoptera; Bottom Right: courtesy of CDK Mobile Systems

eVTOL aircraft of different types and from different manufacturers may be used during humanitarian missions. Therefore ensuring that these aircraft are simple and reliable to minimize downtime and to ensure maintenance can be performed easily by any technician is important. Further, adopting a standard connector for recharging batteries would simplify logistics. SAE International is developing a standard charging interface for electric aircraft called: *AS6968 Connection Set of Conductive Charging for Electric Aircraft* [ref. 43].

Similarly, although most eVTOL aircraft will be designed for autonomous flight, it is possible that some missions will be piloted to facilitate flight safety. As most eVTOL aircraft are computer controlled to provide vehicle stability in all flight conditions, so pilots are mainly providing commands to the flight computers/controllers. It may even be the case that due to the automated simplicity of modern eVTOL aircraft, local personnel may be trained to fly on the spot, as suggested by Sikorsky Matrix Technology [ref. 44] (where 40 minutes is sufficient for anyone to fly a helicopter safely) and by MyCopter project of the European Community, www.mycopter.eu [ref. 45] (where less than 5 hours was sufficient for anyone to fly a vertical flight-capable vehicle).

4) Potential Benefits and Use Cases

By integrating short-range on-demand air mobility systems within the disaster relief efforts, we can enhance the economic and human efficiency of the missions. More importantly, with more timely delivery of food, water, and medicine as well as rapid transportation of patients, we can reduce the disaster-induced casualties in the future.

- **More efficient delivery of food, water, and medicine**. This is due to the vertical flight and landing capability in multiple locations closer to the disaster areas, which enables the delivery of essential supplies in a much quicker manner. The timing can be critical in the prevention of further casualties and can prevent disasters from becoming a more significant problem that requires huge effort and resources to overcome.
- **Safer and more effective medical transport operations**. eVTOL aircraft can deliver medical personnel to the target locations much closer to the persons needing help. The ability to transport patients back to staging areas from a disaster zone adds significant

capabilities in the relief operation. The potential of sending an eVTOL aircraft in autonomous or semi-autonomous mode into a target zone to extract injured persons means more air vehicles can be launched with less risk to medical professionals and can therefore help more people.

- **Financial.** The ability to close the gaps of the last-mile mobility can significantly reduce costs. The financial benefit could account for billions of dollars when such systems are fully implemented. Current rescue helicopters require the resource to be dedicated to these activities and crewed by highly trained operators. High levels of training and crew coordination between the rescue pilots, rescue crews and medical personnel are required. The use of civilian eVTOL aircraft reduces the requirement for dedicated rescue assets to be initially funded, continuously crewed and maintained.
- **Public recognition and goodwill.** With timely actions during disaster relief, the public will recognize the attention and the efforts put forth by the government, the agencies and the regional/local organizations.
- **eVTOL industry growth**. The goodwill generated by these types of Public Services applications can pave the way for broad-based public acceptance of eVTOL aircraft, further enhancing the industry growth by creating additional market and applications beyond air taxi. The expansion of the industry can generate additional tax revenue as well as building a US-leading new industry for long term growth.

5) Efforts Needed, Risks, and Mitigation Measures

Efforts

Plan and fund a pilot program to demonstrate and evaluate the effectiveness of using eVTOL aircraft to add disaster relief efforts. This requires partnership and funding for government agencies and commercial companies to develop mission-tailored air vehicles and systems.

Tasks and Timeline

There are many approaches we can take to enable progress leveraging eVTOL system for natural disasters response and humanitarian aid missions; the phased path forward tasks could include the following:

- Planning and assessment
- Funding plan and solicitation OEMs to support the pilot program
- Establish partnership in the vehicle, operations, and logistic
- Prototype vehicle and system testing & demonstration
- Mission specific vehicle modification & development
- Pilot deployment and trial operations
- Expand operating envelops and missions

As mentioned before, the actual timeline would depend on the industry progress, certification for specific missions and public-use approvals, and end-users/government/international agencies' collaboration. One of the challenges is that the operations are often over the populated areas; therefore, overall system reliability and safety to the people in the vehicle and on the ground are essential. That said, some of the missions, especially with unmanned logistic functions, can be managed to avoid crowded areas to minimize risks. It is envisioned that a phased implementation to match the maturity level of vehicle and system would allow practical and successful deployments. Based on the industry progress to date, initial unmanned logistic trial missions could start as early as the 2022-2023 timeframe, while large-scale manned missions are more likely to occur in the 2025-2027 timeframe.

Risks and Risk Mitigation

- **Technology integration and reliability**. The eVTOL technology, vehicle integration, and operations are new, so uncertainties exist. We should deploy the system in an autonomous mode first for missions like raft delivery in floods or food and medical deliveries to victims in natural disasters. This should be followed by evacuation of firefighters over short distances when necessary and thereby lower perceived risks when public trust in these devices has not yet been established. This technology should be deployed for civilian evacuation after sufficient experience is gained and the system has matured to the level deemed acceptable by the community.
- **Vehicle development and testing**. For vehicle developers, air vehicles will be designed for their primary role but tailored for the missions mentioned above. The eVTOL system safety assessment and redundancies built into the air vehicles are unchanged, but additional safety can be further enhanced by customizing the flight computers specifically for the missions and operations.
- **Inter-agency coordination and operations**. This is a new capability that did not exist in the past; it will take close coordination between OEMs, agencies and local community corporation to make the system function as intended. Risks can be mitigated by careful planning, pre-deployment communications, training and education of the new system capabilities, and understanding the limitations and operational capabilities before actual deployment. The selection of missions and locations is critical to ensure success.

CASE 3: Medevac

Air ambulance airplanes and helicopters have become part of everyday life in the United States and the rest of the world. The origins of the air ambulance for transportation by airplane of ill and injured people probably originated in the First World War when injured soldiers were transported from areas of operation to makeshift hospitals. The use of civilian aircraft dedicated to air ambulance operations is reported to have begun in Australia in 1928 with the formation of the Australian Inland Mission Service (now the Royal Flying Doctors) and with operations starting in the United Kingdom in 1933 using the De Havilland DH89A Rapide [ref. 46].

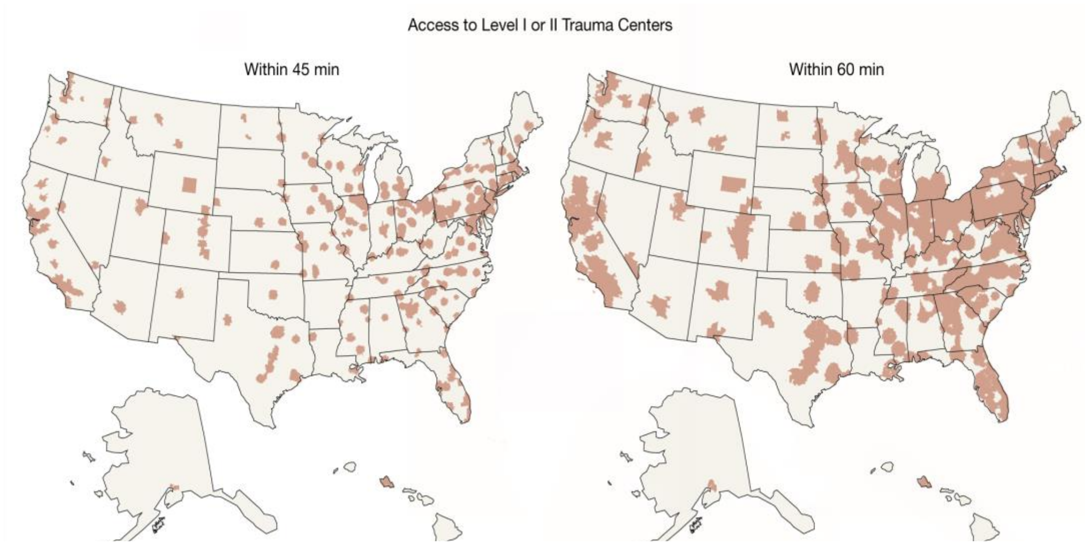


Figure 21. Access to Level I and Level II trauma centers in the United States. Image courtesy of the Association of Air Medical Services and Medevac Foundation International

The development of helicopters with improved payload capabilities in the 1940s through 1960s led to the widespread use of helicopters for the movement of injured troops during the Korean War (Bell H-13 and Bell 47 MASH helicopters [ref. 47]) followed by the Vietnam War. In modern times, when circumstances require urgent medical attention, the air ambulance has become a significant sector within the aviation industry. Modern medical transport aircraft are now equipped with highly specialized equipment and are capable of carrying multiple patients to the point of care. A mixed fleet of aircraft can be used, depending upon the nature of the medical transportation and the level of care required. These can vary from modern helicopters to fixed-wing turboprops,business jets, and large transport airplanes. For example, Orbis is flying its Flying Eye Hospital in a DC-10 since 1982 offering a state-of-the-art teaching facility complete with operating room, classroom and recovery room (https://gbr.orbis.org/en). The business model used to deliver this essential service are many and varied. Private, corporate and on-demand carriers provide 'generic/unmodified' aircraft for air ambulance services. Transportation of patients and carers en route may be between cities, from remote locations or within cities from accident locations to hospital trauma centers or care. Some operators are affiliated with specific trauma centers operating from dedicated heliport's whereas fixed-wing aircraft generally operate from licensed and unlicensed airfields and unprepared airstrips.

A typical airplane configuration for ambulance operations may include medical oxygen, backroom/via systems and litter systems (e.g. stretches and patients restraining devices). Supplemental lighting may also be fitted such as searchlights, internal lighting for medical procedures [ref. 48]. They may also be required to carry medical equipment power outlets, balloon pumps, and special air ambulance communication equipment. US Army Medivac helicopters are equipped with internal litter kits that can be electronically managed. As with all aircraft, specific minimum equipment list must also be maintained for safe operation within required missions.

While helicopters have limited endurance and range when compared with fixed-wing counterparts, they offer greater flexibility and adaptability in reaching the patient at the accident scene for frontline air ambulance operations. Emergency medical services using both airplane and helicopter operations face significant environmental challenges. Pilots are required to fly to remote locations surrounded by terrain using available navigational aids sometimes requiring landing on unprepared surfaces in darkness and inclement weather.

Previous studies have reported that the number and distribution of trauma centers are uneven across the United States, suggesting large differences in access to trauma center care exist [ref. 49]. This highlights the need for expedient service in less populated regions outside of major cities. Traffic congestion within major cities can also lengthen ground ambulance response times.

Business Models

Within most countries, three air ambulance business models exist:

- Operator-owned (community-based/charitable trusts)
- Hospital-owned (traditional or hospital-based)
- Government-operated, or public use

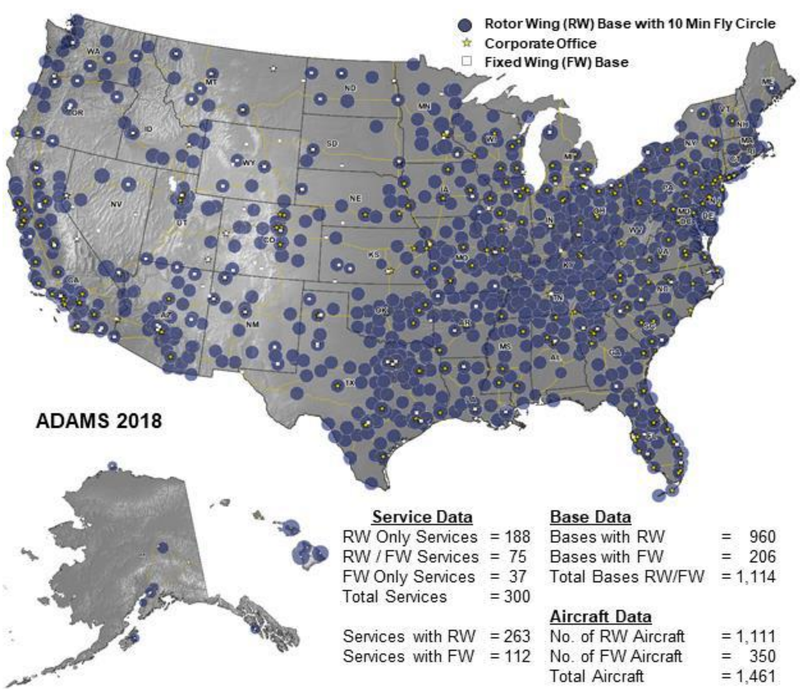


Figure 22. USA national map, Air Medical Services. Image courtesy of Dr. Charles Branas, Columbia University

Increasingly, mixed models are apparent as hospitals share more of the financial risk and lease or purchase aircraft. The basic difference between hospital and community-based operators is who owns the service [ref. 50]. In a hospital-based service, the hospital owns the asset and provides medical direction, nurses and paramedics and billing. The hospital pays the operator a fixed monthly fee retainer, plus a pay-as-you-go flight-hour fee. The operator receives revenue whether or not the aircraft operates as the fixed overheads of operating a helicopter and support services are high. Under a solely community-based model, the air medical service typically is owned by the operator who hires or contracts out the medical directors, paramedics and flight nurses, provides the aircraft, pilots and mechanics and patient billing. Revenues are largely dependent upon the number of flight hours [ref. 51].

1) Problem Description

Air medical transport provides numerous advantages over ground transport, namely increased speed and flexibility. Ground transport is limited by factors such as the availability of roads, road conditions and traffic. It also moves slower than air transport, especially when compared to fixed-wing aircraft.

However, there are also several disadvantages to air medical transport common to both fixed-wing and helicopter or specific to each type. The increased cost depends on many factors such as crewing, type of aircraft, accessibility to airport runways for airplanes, and distance of transfer. The cost of operating air medical transport is also very high because the aircraft itself can cost several million dollars, and the maintenance is strictly regulated by the FAA [ref. 52] or other aviation agencies in different countries. Air transport is more susceptible to adverse weather conditions than ground transport. In addition, weight is a greater limitation for air transport than ground transport particularly when assessing the power required for VTOL operations.

The challenge is how to provide safe, efficient air ambulance transportation at a lower cost to enable broader geographical coverage and improved levels of service in urban areas.

2) The Current Approach and Challenges

Cost

In the United States the relative cost-effectiveness of helicopter and land ambulance services varies with:

- Geography (size of the area covered, terrain, climate, daylight hours)
- Population density
- Access to other (alternate) medical services
- Types of accidents/incidents which might benefit from the rapid response

Other countries and regions in the world will differ [ref. 53].

Safety

The nature of air medical transport, which is dominated by Helicopter Air Ambulance (HAA, formerly known as HEMS [ref. 54]) involves operations in adverse weather, challenging environments, during day and night. This exposes the crew to additional risk factors which is the principal reason why historical accident rates for on-demand 14 CFR (Code of Federal Regulations) Part 135 HAA (HEMS) operations are higher than 14 CFR Part 121 scheduled commercial operations [ref. 55].

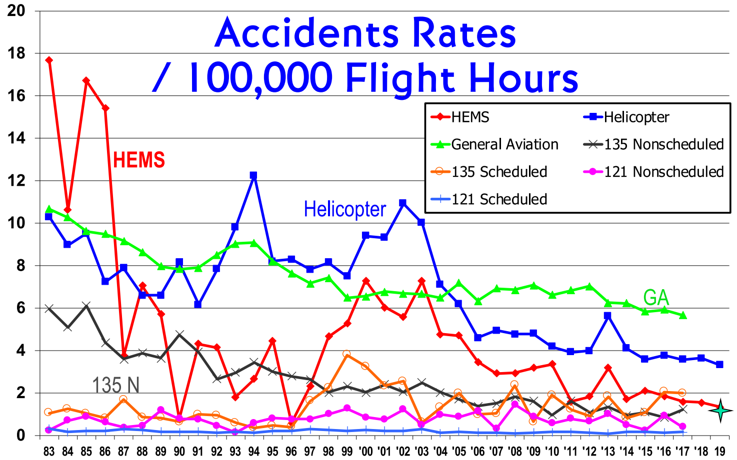


Figure 23. Comparison between HEMS and helicopter accident rates. Figure courtesy of Dr. Ira Blumen, University of Chicago

Landing Zones

Helicopters are capable of landing close to the scene of the accident/incident, sometimes landing on roads or open fields [ref. 56]. Suitable landing zones are typically 100 square feet and are subject to usual checks for suitability (size, shape, slope, surroundings, and surface). Where ground support is available, first responders may mark out the area for the helicopter crew and provide security to bystanders by keeping them a safe distance from the landing area. Support and ground crews are trained on landing zone safety so that they do not put themselves or the helicopter crew in danger by being struck by the main rotor or tail rotor (note, this is one big advantage of eVTOL aircraft in that the rotors or propellers can be easily stopped and restarted since they are driven by electric motors rather than thermal engines). Helicopter crews are trained for ingress/egress on the scene with pilot approval. This may occur with the aircraft shut down or with the rotors turning ('hot load' or 'hot offload' respectively). The pilot in command has the final call on landing zone safety. Obstacles can create a safety hazard, e.g. overhead cables/power lines, crowds of people, cell phone masts, street lamps, road signs or the quality type of landing surface itself and weather effects(rain/snow/ice, etc.). Landing in a muddy field can cause the landing gear or skids to sink into the mud, making takeoff difficult when fully loaded (e.g., dynamic rollover). Loose objects or debris also represent a hazard since downwash of the main rotor blades can blow objects into the air, creating foreign object debris (FOD) that can strike ground personnel, main rotor or tail rotor blades or get sucked into the engines.

Weather

Weather conditions are a risk factor for air medical transport. Aircraft are susceptible to strong winds and/or heavy snowfall as well as low visibility due to inclement weather, dust or sand. Pilots fly by Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) set by the FAA in US. Aircraft operating under these rules must abide by the limits of operation contained in these rules and the aircraft itself may also be restricted to certain types of operation (non-icing conditions, daylight only, etc.). Aircraft operated in VFR conditions must have clear visibility of several miles depending on the altitude and type of aircraft. Although safety/guidance systems may be installed, pilots are still required to adopt 'see and avoid' principles to avoid collision with other aircraft or objects on the ground.

Crew

Crews for air medical transport may vary in numbers and types of skills. This may be:

- one or two pilots (depending upon the operator's standard operating procedures and area of operation)
- medical personnel (paramedics, nurses, physicians, or respiratory therapists, etc.)

The aim is to minimize human error through teamwork. Crews may also be trained for the type of equipment on their specific aircraft (e.g. night vision goggles, use of spotlights, winches, etc.). Medical personnel may have additional training for special practices (e.g. pediatrics, neonatal).

3) Using eVTOL Aircraft

Lower capital costs and lower predicted operating costs for eVTOL aircraft could present new opportunities for the use of air vehicles in short-range operations in the Medevac sector. There are three basic concepts of operation:

a) **First Responder**
First responder [ref. 57] missions may be possible in intra-city environments where traffic congestions and response within the "golden hour"—the first hour of critical care following an accident/incident [ref. 58].

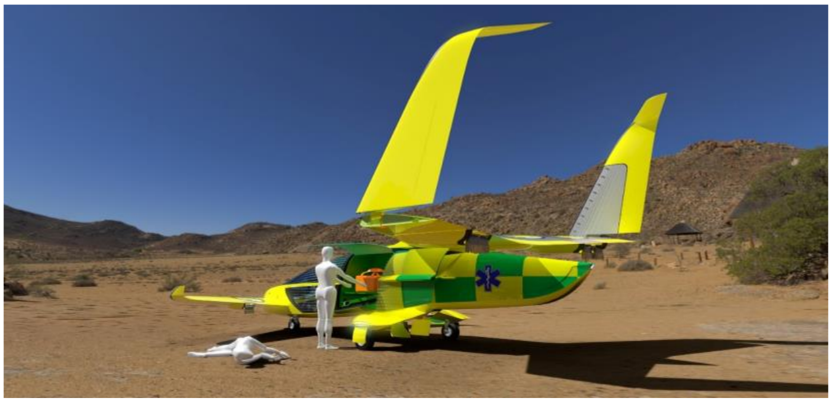


Figure 24. First responder eVTOL concept vehicle. Image courtesy of Dean Mangurenje and Dr. Mike Bromfield, Coventry University, UK

b) **Air Ambulance (Emergency)**
For medium range operations, eVTOLs may replace helicopters if they are capable of achieving similar range and endurance with comparable payloads. The carriage of specialist medical equipment to support the required missions is essential.

Figure 25. Bell Nexus envisioned for medical transport missions at a hospital. Image courtesy of Bell

c) **Air Ambulance (Nonemergency)**
For longer range operations and transportation of non-critical-care patients, eVTOLs are unlikely to be able to compete with fixed-wing air ambulances in the short/medium term. Helicopters are also rarely used for this mode.

Although the market size for application of eVTOL aircraft is smaller than that of commercial air taxis, the social benefits are more significant. They may offer opportunities to provide increased levels of service coverage at a lower operating cost when compared to helicopters with similar crewing requirements.

4) Potential Benefits

The use of short-range on-demand air mobility in medevac could enhance mission capabilities resulting in more lives being saved within the 'golden hour'. The medevac market is limited in terms of market potential but high in market value.

- **Smaller footprint**. First responder eVTOL aircraft may have a smaller physical footprint leading to wider access in restricted areas, city environments.
- **Faster response within the 'golden hour'.** Use of eVTOL aircraft in the first responder role and more eVTOL aircraft to compliment helicopters could improve Public Services.
- **Save more lives**. By providing more air vehicles with broader geographical coverage more lives could be saved in urban and intra-urban areas where traffic congestion is a major problem. Such air vehicles could also be used in disaster situations for mass transportation of casualties.
- **Financial**. Through large scale production, eVTOL aircraft may have lower capital costs and annual operating when compared to helicopters.
- **High levels of public acceptance of eVTOL aircraft**. The use of eVTOL aircraft for medevac Public Services could enhance acceptance of these types of vehicles by the public and lead to more extensive applications by local communities and government agencies.

5) Efforts Needed, Risks and Mitigation Measures

Efforts

Plan and fund a pilot program to demonstrate and evaluate the effectiveness of using eVTOL aircraft to enhance medevac capabilities. Define the Concept of Operations (CONOPS) and operating boundaries for **one** preferred mission and use this to lead the project. Define, scope, objectives approach, deliverables and required resources to complete. This will require collaboration and funding by government agencies and commercial companies to develop mission-tailored air vehicles and systems.

Tasks and Timeline

There are many approaches we can take to enable the progress leveraging eVTOL system for medevac operations; the phased path forward tasks could include the following:

- Planning and assessment
- Funding plan and solicitation OEMs to support the pilot program
- Establish partnership in the vehicle, operations, and logistic
- Prototype vehicle and system testing & demonstration
- Mission specific vehicle modification & development
- Operating reliability and safety review
- Pilot deployment and trial operations
- Expand operating envelops and missions

The actual timeline would depend on the industry progress, certification, and end-users/government agencies' collaboration. For first responder/medevac operations, overall system reliability and safety to the people in the vehicle and on the ground are essential. For many of the proposed missions, semi/full autonomy will be needed to minimize the training required and provide operational flexibility. Initial trial operations are likely to be in selected rural/remote areas with very low population density to reduce risks. A phased implementation to match the maturity level of vehicle and system would allow practical and successful deployments. Based on the industry progress to date, initial trial missions could start as early as the 2024-2025 timeframe (heavily driven by certifications), while expanded implementation are more likely to occur in the 2026-2030 timeframe.

Risks and Risk Mitigation

- **Aircraft performance limited by weight**. The use of eVTOL aircraft for medevac operations requires the carriage of specialized medical equipment and personnel, adding to the aircraft basic empty weight, limiting range and endurance. This would require performing a detailed mass and balance study and the extensive use of light-weight material in the air vehicle design.
- **Safety and reliability**. A 'safety by design approach' should be used in conjunction with COTS technologies, where practical for expediency. Required target levels of safety should be at least equivalent to those required for existing HAA operations.
- **Vehicle development and testing**. For vehicle developers, due consideration needs to be given to specialized equipment requirements for the missions identified. Since these air vehicles will be required to operate in similar weather conditions to helicopters day and night and all-weather ops capabilities are desirable. Patient comfort and ride quality will also be specific to this environment thus requiring additional safety considerations when compared to 'commercial air taxi' operations. Risks for all-weather operations can be mitigated by the installation of appropriate lightweight safety systems.
- **Inter-agency coordination and operations**. The provision of first responder missions is a new capability and will require coordination with existing medevac HAA operations, OEMs, other emergency services, agencies and local communities for efficient operations. Risks can be mitigated by a phased implementation considering, personnel, data and system requirements. A 'pilot' project approach should be used with limited locations/bases to 'learn lessons' before broader implementation.

CASE 4: Law Enforcement and Public Safety

1) Problem Description

Across the United States there are almost 18,000 agencies and over 1 million sworn and non-sworn officers, who primarily provide law enforcement through government police agencies. These include Federal Law Enforcement Agencies, County Sheriff, City and State Police Departments with roles to protect life and property, provide law enforcement, first response to emergencies and public safety threats, maintain public order and form part of the criminal justice system.

Police and law enforcement personnel regularly interact with the public and according to the 911 Association NENA[11] , an estimated 240 million calls are made to 911 each year for law enforcement, public safety, fire and EMS matters.

Modern policing and law enforcement require the use of modern technology. Its introduction is often influenced by time, ingenuity, community needs, financial constraints and available technology. Over the years policing activities have been assisted by technology advances ranging from the introduction of radios in police vehicles through the digital transfer of information by onboard computers. As part of this technology advancement, fixed-wing aircraft and helicopters have provided law enforcement presence in the air modifying policing behaviors.

When analyzing the effectiveness of aerial assets for law enforcement, the current use of either manned or unmanned systems provides a force multiplier effect enhancing the safety of law enforcement/public safety personnel and citizens.

2) The Current Approach and Challenges

Police helicopters were first introduced by the Los Angeles Police Department Air Support Division in 1956. There are now approximately 300 Air Support Units operating in the United States and a large number in other parts of the world. While many of the aircraft used carry armed officers and can land in otherwise inaccessible areas, they are a limited resource with high operating costs, limited trained personnel, high entry and training requirements, proportionate risk. They are generally used for aerial surveillance, reconnaissance and support for ground personnel. Additional capabilities such as high-risk response or SAR insertion or recovery require additional skills, training and equipment which in turn often makes them an even more limited resource than surveillance or reconnaissance aircraft.

Figure 26. Police air support. Image: Pixabay

In recent times an increasing number of law enforcement agencies have commenced introducing sUAS to support the delivery of law enforcement and public safety services. sUAS provide an economical option and can be used in many similar situations to traditional manned aircraft.

[11] NENA – National Emergency Number Association (https://www.nena.org) is the professional organization solely focused on 9-1-1 policy, technology, operations, and education issues. NENA promotes the implementation and awareness of 9-1-1, as well as international three-digit emergency communications systems.

sUAS equipped with high definition cameras for photography, video and thermal imaging provide law enforcement officers an advanced 'bird's eye' view of a situation or location and allow first responders to more judiciously and safely enter a threat area.

While the introduction of sUAS, as with manned aviation assets, is providing irrefutable evidence of their benefits in supporting police and security operations, the fundamental problem of optimizing service delivery still remains. sUAS operations still require advanced training, additional skills and a law enforcement officer to operate knowledgeable in their operations. Federal regulations controlled by the FAA require approvals or formal pilot qualifications for their operation in the national airspace. Many agencies are now establishing separate sUAS units similar to manned air units to support core law enforcement and public safety services.

Figure 27. Police launch sUAS. Image: Wikimedia Commons

This means that with the use of sUAS there is now another facet in the law enforcement process that must be integrated into service delivery. In multi-unit response situations operational resources must work closely together. In a single unit response, for the officer to gain the benefit from a sUAS, they must perform both the sUAS and traditional policing functions together and potentially risk degrading one of these functions due to the increased workload with an attendant potentially have an adverse effect on the officer and public safety.

3) Using eVTOL Aircraft

Numerous law enforcement and public safety missions can be performed by eVTOL aircraft with increased effectiveness and safety:

- **Search and Rescue (SAR).** Insertion of trained personnel and evacuation of located persons and casualties can be performed using a higher number of assets.
- **Disaster response and management.** The ability to provide more aerial assets especially during the pre-event or immediate post-event period when resources are generally most limited.
- **Tactical response.** Increased numbers of specialist officers can be transported by air.
- **Crime scene reconstruction.** Mapping, photographing and digital reconstruction can be achieved in reduced time
- **Other functions.** Increased number of aerial assets for communications relay, airborne command and control and a video streaming aerial platform.

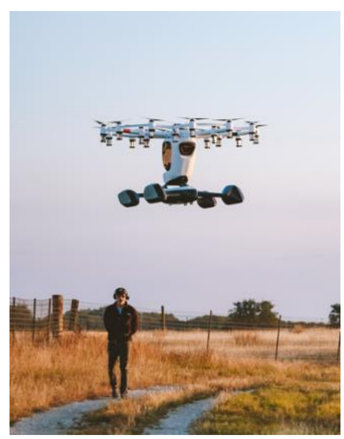


Figure 28. Small eVTOL can be useful in specific tasks and environment. Image courtesy of LIFT Aircraft

4) Potential Benefits

eVTOL aircraft with high levels of autonomy and lower training requirements could provide more officers with an aerial capability across an increasing number of law enforcement and public safety applications which can increase officer and public safety such as:

- **Increased force multiplier effect.** More officers can have access to aerial capability with reduced initial training, skills maintenance requirements and potential cost savings.
- **Faster response times.** More available dedicated and non-dedicated aerial assets to transport non air unit officers.
- **Increased first response capability to emergency situations.** Any officer can respond to any emergency situation more quickly.
- **Surveillance and reconnaissance.** More officers can have access more readily and directly to eyes-in-the-sky aerial observation data including infrared scanning, increasing firsthand situational awareness and effectiveness.
- **Increased safety during pursuit activity.** The ability to deploy a sUAS from an active vehicle or during foot pursuit to provide in conjunction with eVTOL system enhanced situational awareness surveillance and accelerate interception and apprehension.
- **Reduced traffic-induced delay.** Officers can avoid high levels of ground traffic congestion.

The main benefit of eVTOL aircraft is that they provide the capability to directly access and utilize aerial delivery of their services for an increased number of police and law enforcement officers.

Figure 29. GoFly competition, Pratt & Whitney Disrupter Award winner, teTra 3. Image courtesy of Johnny Doo

Officers utilizing eVTOL aircraft who may be called on to ultimately provide the ground-based functions can first obtain the "bird's eye" view themselves without reliance on other assets or distraction from their core policing functions. Real-time direct first-person situational awareness can be maintained compared against relayed information from a manned aircraft or compensating for the time difference, however short, between ceasing the sUAS operations and initiating the intervention function.

High levels of real-time situational awareness directly enhance officer and public safety. eVTOL aircraft provide this opportunity right up to the time a decision to act or intervene is made. Continued air support remains important when a ground-based officer acts, and in the case of this officer arriving in the first responding eVTOL aircraft, a second eVTOL aircraft could be used to continue the air support function.

Figure 30. Deployment flexibility and point-to-point fly offers much faster response, especially when roadway travel is exceptionally time-consuming. Image courtesy of Johnny Doo

There are sometimes privacy concerns with the use of aerial assets which can be seen to overshadow the technology benefits despite their proven effectiveness. eVTOL aircraft potentially have the ability to mitigate these concerns as the community engagement that occurs following the appearance of an aerial asset would most likely be by the officer who was on board the eVTOL aircraft in the first instance.

While we recognize the high levels of skill and commitment required by police and law enforcement officers who often performing dangerous duties, there are obvious benefits from the introduction and use of eVTOL aircraft in policing and law enforcement activities. Dedicated police and law enforcement autonomous eVTOLs or the ability for police and law enforcement officers to commandeer any available and suitable eVTOL aircraft in an emergency situation provides the opportunity for increased and more frequent aerial policing and law enforcement capability with subsequent benefits to officer and public safety.

Overall, aerial assets do provide clear benefits in supporting police operations and eVTOL aircraft are the next step in the provision of aerial support for police and law enforcement agencies.

5) Efforts Needed, Risks, and Mitigation Measures

Efforts

Plan and fund a pilot program to demonstrate and evaluate the effectiveness of using eVTOLs for law enforcement and public safety. It requires partnership and funding for government agencies and commercial companies to develop mission-tailored vehicles and systems.

Tasks and Timeline

There are many approaches we can take to enable the progress leveraging eVTOL system for law enforcement and public safety operations; the phased path forward tasks could include the following:

- Planning and assessment
- Funding plan and solicitation OEMs to support the pilot program
- Establish partnership in the vehicle, operations, and logistic
- Prototype vehicle and system testing & demonstration
- Mission specific vehicle modification & development
- Operating reliability and safety review – public areas
- Pilot deployment and trial operations with selected agencies
- Expand operating envelops and missions

Same as the other use-cases, the actual timeline would depend on the industry progress, certification, and end-users/government agencies' collaboration. As law enforcement and public safety missions are typically taking place in populated areas, overall system reliability and safety are essential for successful implementation. Like the medevac missions, semi/full autonomy capabilities will be needed to minimize the training required and provide operational flexibility. Initial trial operations are likely to be selected tasks to remote locations without large crowds, then expand operations based on lessons learned on best practices. It is envisioned that a phased implementation to match the maturity level of vehicle and system would allow practical and successful deployments. Based on the industry progress to date, initial trial missions could start as early as the 2024-2025 timeframe (heavily driven by certifications), while expanded implementation are more likely to occur in the 2026-2030 timeframe.

Risks and Risk Mitigation

- **Technology integration and reliability**. eVTOL technology and air vehicle integration and operations are relatively new and uncertainties exist. We should immediately promote the development of 5G vehicle-to-vehicle (V2V) communication for enhanced autonomous detect and avoid (DAA) airspace deconfliction when multiple UAS are supporting tactical operations. This would enhance, for example, deployment of multiple autonomous surveillance and reconnaissance sUAS to significantly increase situational awareness for engaged officers. Increased situational awareness and timely intelligence are fundamental to command and response decision making and the incorporation of this feature will be extremely beneficial. Near term development and deployment of these technologies will accelerate application in eVTOL aircraft for human transportation systems.
- **Vehicle development and testing**. For vehicle developers due consideration should be given to specialized equipment requirements for the missions identified. These law enforcement UAS will be required to be deployed rapidly in unfamiliar theaters of operation. Potential first response deployments can include high risk tactical or containment situations where officers currently have well-developed procedures and protective equipment including firearms and personal body armor. Consideration needs to be given to the increased weight required and personnel restraint requirements as a result of this additional equipment and the security of firearms in an air transport situation. Further, micro UAS are needed that can be deployed by officers engaged in foot pursuit to provide enhanced situational awareness for interception and apprehension. This requires both the autonomous air vehicle and lightweight visual device such as a wristwatch monitor or weapon-mounted sight.
- **Inter-agency coordination and operations**. This is a new capability that is near-term realizable. It will take close coordination between OEMs, regulators, and law enforcement agencies to make it work as intended. Risks can be mitigated by careful planning, pre-deployment communications, training and education of the new system capabilities, and understanding the limitations and operations before actual deployment. Selection of missions and locations is critical to ensure success. Law enforcement agencies are increasingly engaging their communities when adopting new technologies to develop trust and mutual respect and balance privacy with maintaining safety. Any inter-agency coordination for the introduction of eVTOL aircraft for law enforcement should also consider empowering these agencies with sufficient information and strategies to ensure the community is engaged successfully.

CASE 5: Last-Mile Aerial Delivery

eVTOL aircraft-based last-mile aerial delivery system can be one of the most significant game changer in near-and long-term applications. As demonstrated in UAS designs, the autonomous delivery system is very much a viable technology even though delivery to the residential area may still be subject to local and state law considerations. For Public Services, last-mile delivery would be an ideal initial mission for an eVTOL aircraft as many of them have autonomous[12] capabilities designed into the vehicle and are capable of providing short to medium range delivery capabilities without runways (VTOL mode). While carrying people for Public Services mission would require a much more conservative approach and practice, equipment and supply delivery for selected missions in military logistics and disaster emergency deliveries would be a logical initial application with relatively low risks.

Figure 31. Logistic functions as illustrated by Bell's family of eVTOL platforms. Image courtesy of Bell

The unique characteristic of an eVTOL aircraft is that it offers cost-effective short to medium range distributed aerial delivery capabilities. For the military, the system can provide frontline resupply capabilities with some designed to be positioned in the forward operating bases. The low noise and small size of certain designs could enable the vehicle to reach the frontline troops rapidly for on-demand logistics. After the system has demonstrated sufficient reliability, the vehicle could then be adapted to be quickly converted to a patient transport configuration to retrieve wounded soldiers and deliver them to the field hospital during the "golden hour" of survivability [ref. 59].

In disaster response and humanitarian aid operations, the capabilities and flexibility of an eVTOL platform can provide valuable-distributed on-demand supply delivery of food, water, blanket, and medical supplies. Many eVTOL platforms are designed to be able to take off and land in unusual sites such as schoolyards, shopping mall parking lots and even on neighborhood streets. An eVTOL aircraft can deliver packages directly to the survivors and people in need. As discussed in Case 1, when fighting either a wildfire or neighborhood building fire, eVTOL aircraft can complement the firefighting operation by delivering needed equipment directly to the firefighter, providing critical and timely support.

1) Problem Description

When providing disaster relief, humanitarian aid, medical supply or military logistics, one common challenge is the last-mile short-range on-demand transport capabilities. Current air logistics systems have either large payloads, long-range or heavy lift vertical delivery capabilities. However, the short to medium range smaller payload delivery (up to 1,000 lb. class) to the location when needed is not well served with the currently available vehicles. The acquisition and operating cost of most current aircraft or helicopters are too high for large scale acquisition and deployment. With the limited number of flight vehicles, though very capable, not

[12] Here the term *autonomous* means autopilot waypoint-following, auto-take-off and auto-landing but not deep learning AI decision making. Autonomous also means automatic deconfliction using a sequential library of evasive maneuvers rather than machine learning. This enables deterministic rather than probabilistic deconfliction.

being positioned in many cases where they are needed or too remote to be able to deliver supplies to the location of need, presents a challenge for mission timeliness.

2) The Current Approach and Challenges

Currently most missions of disaster relief, medical supply, last-mile logistics are performed with manned airplanes or helicopters. Some sUAS are now being evaluated and deployed to complement their capabilities. Long range fixed-wing transports can only deliver needed supplies to a nearby airport that is not damaged by the disaster. Helicopters, when available, can deliver to somewhere closer to the target area though sometimes limited by landing zone conditions. All of these missions are operated by pilots and flight crew aboard often with long fatiguing missions in which human capacity and endurance become a challenge. UAS can help in this situation, but many delivery-capable UAVs are too small in payload for large scale mission requirements.

Helicopters are not always readily available when needed, depending on station locations, logistics and flight/ground crew support limitations. For military operations, delivery or resupply can be done by helicopters or surface vehicles (including boats, rafts, etc.). Helicopters and their crew are at risk when operating in a battlefield as they are apparent targets with the acoustic signature that can be detected at a distance. Surface vehicles are much slower and vulnerable; the terrain may not allow easy access by ground either.

Figure 32. Delivering supplies—team unloads supplies from a US Army CH-47 Chinook helicopter at the port of Roseau, Dominica, 2017, in the aftermath of Hurricane Maria. Image: US Army

For humanitarian aid, disaster response and other Public Services missions like firefighting and medical deliveries, these are often limited by available helicopters and fixed-wing air transportation capabilities for airdrops. Alternative means require many days of effort with significant manpower clearing blocked roadways to reach the target area. In situations like an earthquake or tsunami, the bridges and roadways are often damaged and not repairable for weeks or longer. The need for a short-range last-mile cost-effective delivery system is needed.

3) Using eVTOL Aircraft

Some of the key missions for the eVTOL system that can significantly enhance our abilities to deliver equipment and supplies include:

a) Military last-mile delivery and resupply

Adding eVTOL capabilities into the current logistic system can significantly enhance the medium-small package/cargo delivery to the frontline in a timely manner, since the eVTOL aircraft is less complex to operate and maintain. By selecting road transportable eVTOL designs for these missions, the readily available units can be deployed at the forward operating depot enabling distributed on-demand operations to enhance mission capabilities.

Figure 33. Bell's 70 lb. payload eVTOL autonomous pod transport, APT70. Images courtesy of Bell

The eVTOL aircraft should also be more cost effective as compared to a helicopter, tiltrotor or other means of air delivery platforms available today. Hybrid-electric power systems would provide an extended range for eVTOL aircraft and allow logistics to support the operations (diesel or jet fuel) without requiring separate charging stations. Without pilots or flight crew on board, the risk of the last-mile delivery missions can be significantly reduced. With smaller size, lift system redundancy, and low noise, eVTOL aircraft can provide significant enhancement in mission success rate. Ship-to-shore deliveries may also be well-suited for application of the eVTOL aircraft.

Figure 34. eVTOL has the potential to be used for offshore re-supply and other missions in addition to air taxi and air ambulance operations. Image courtesy of Airbus

b) Offshore resupply

Offshore cargo BVLOS transport operations up to 200 NM to shallow water oil platforms and some near-end deep water platforms offers significant commercialization opportunity.

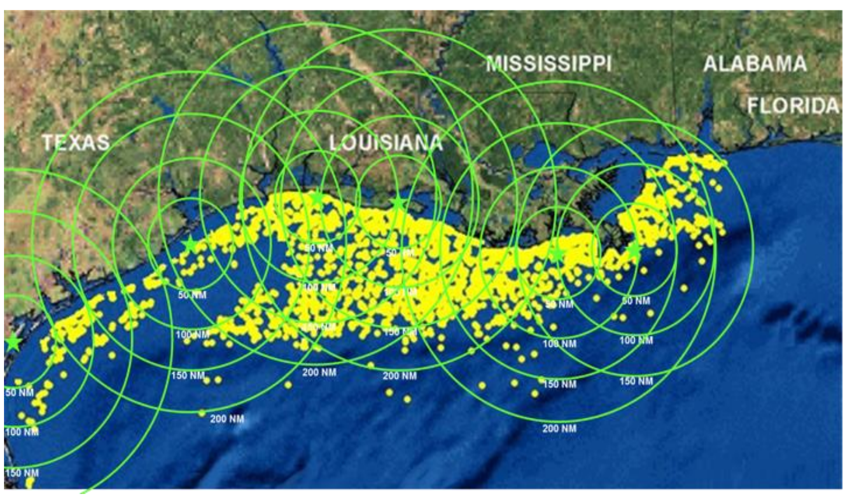


Figure 35. Offshore cargo transport via UAS in the Gulf of Mexico. Image: NOAA

The direct operating cost of UAS delivery can be less than half the cost of delivery via helicopter and can be expeditiously dispatched to deliver time-critical components and equipment. UAS flights initiating from existing flight operations centers can fly along paths offset from and yielding to manned flight paths, remaining in coordination with cooperative regional air traffic. While the airspace is relatively uncrowded, DAA as well as redundant command and control (C2) remain essential safety technologies since these flight paths are dynamic within this operational theater.

c) Humanitarian aid and disaster response

For humanitarian aid and disaster logistics missions, eVTOL aircraft can complement the existing fleet of helicopters to enhance on-demand aerial delivery capabilities. The reduction in time required to deliver critical supplies like food, water, and medical supplies into disaster area is critical in saving lives and taking care of the injured. When roadways to the disaster area are blocked or when bridges are damaged, eVTOL aircraft can serve as cost-effective and timely on-demand last-mile delivery system.

Figure 36. Delivering supplies to the citizens of Maulaboh, Indonesia after the 2004 Indian Ocean tsunami. Image: US Navy

d) Firefighting and police work

By incorporating the vertical takeoff capabilities to and from many more locations not limited by traditional airports, eVTOL aircraft can deliver fire retardant, firefighting equipment, and supplies to the site where it is needed. These delivery capabilities can be applied to fighting wildfires as well as an urban building or suburban neighborhood fire. For police work, the ability to deliver communication equipment, medical kits, protective gear, and ammunition to the site when needed can make a significant difference in the outcome.

Figure 37. The A3 Vahana single-seat autonomous demonstrator eVTOL aircraft is the forerunner for an Airbus air taxi short-range aircraft for urban air mobility (UAM). Image courtesy of Johnny Doo

The public uses eVTOL UAS for eyes in the sky at a fraction of the cost of existing rotary wing platforms, and eVTOL UAS can be rapidly deployed on an as-needed basis by field personnel. Airborne cameras include visual spectrum as well as infrared spectrum for thermal imaging enhancement or night vision. Examples include border security for tracking human and drug smuggling, identifying and aiding rescue of stranded persons in hostile or parched environments, and enabling access to inaccessible or dangerous areas that would limit access for field agents and first responders.

First responders can benefit from rapidly deployed UAS to provide first eyes on the accident scene for early accounting for victims, initial assessment of life-care needs, and identification of risks including hazardous materials (HAZMAT) including toxic or explosive organic compounds.

Tethered drone systems offer secure communications and continuous power supply that enable extended operations for security monitoring at practical altitudes up to 50 m above ground level (AGL). Secured communications through direct wire or fiber optic connection overcome cyber threats, multipath problems in urban canyons, and RF-saturated (HIRF) areas that challenge command and control (C2) links. Tethered UAS operations require only vertical deconfliction (e.g., power wires, trees, overhead structures) enhancing air encounter safety. Further, minimal pilot skills are required for tethered UAS operations offering a near-term opportunity for complete autonomous control. Finally, tethered operations with tension maintained on the tether enhances flight stability (i.e., reduced air and ground risk) in turbulent air such as in urban canyons and around firefighting scenarios (structure or wild).

The eVTOL system will not be operating alone; eVTOLs will be integrated into the overall air logistic/delivery system to form a more effective and safer integrated capabilities (see for example the dropping boats capability which improves the search and rescue response of helicopters at [ref. 60])

4) Potential Benefits

By adding short-range on-demand air mobility into the existing aerial delivery system, we can enhance the effectiveness of many missions. More importantly, we can reduce the risk and casualties of manned delivery operations.

- **Mission effectiveness.** On-demand distributed delivery system enabled by eVTOL aircraft can offer timely delivery to the target area that may not be easily accessed by the current air vehicle systems.
- **Lower acquisition and ownership cost.** eVTOL aircraft are designed with electric energy storage and electrical power transmission to drive multi-rotor lift/propulsion units. These systems are low on maintenance and high on durability. This is true unless partial discharge phenomena are present in the high-voltage batteries of the electric motors, in this case, degradation and even breakdown of the electric motor can be triggered [ref. 61]. The vehicle acquisition cost would be much lower than for a helicopter with the same payload capacity and could operate mostly in autonomous mode. Without the onboard pilot and flight crew, the system could be managed with a ground operator – significantly reduce the operating cost. By implementing eVTOL aircraft last-mile delivery for various missions, it is thought that the overall mission effectiveness and total ownership cost would be improved.
- **Reduce civilian and military casualties.** By supplying urgently needed medicine, food, and water to a disaster area, the post-disaster casualties can be reduced. The ability to deliver supplies, equipment to the frontline troops in a timely manner using an autonomous system without the need for pilot and crew on board further reduces potential personnel casualties.
- **Pilot shortage solution.** There is a global pilot shortage which limits the traditional helicopter fleet expansion to support ever-growing aerial delivery mission requirements. Without the need for onboard pilot and flight crew, eVTOL aircraft can be controlled on

the ground while flying autonomously for package delivery operations. In many cases, one controller can manage 10-20 autonomous or semi-autonomous eVTOL aircraft reducing the number of ground controllers needed can be a fraction of the flight vehicle units. Because ground controller training could use a flight simulator (aviation and airspace knowledge still required) without the need to obtain a Part 61 pilot license, this would significantly reduce the pilot shortage problem.

- **Public recognition and goodwill.** Proactively implementing eVTOL aircraft for various Public Service aerial delivery missions which benefit the general public and military operations.
- **eVTOL industry growth.** The goodwill generated by these types of Public Service applications can pave the way for widespread public acceptance of eVTOL aircraft, further enhancing the industry growth by creating additional markets and applications beyond air taxi.

5) Efforts Needed, Risks, and Mitigation Measures

Efforts

Plan and fund a pilot program to demonstrate and evaluate the effectiveness of using the eVTOL system for various Public Services package delivery missions. Requires partnership and funding for government agencies and commercial companies to develop mission-tailored air vehicles and systems.

Tasks and Timeline

There are many approaches we can take to enable the progress leveraging eVTOL system for last-mile aerial delivery missions; the phased path forward tasks could include the following:

- Planning and assessment
- Funding plan and solicitation OEMs to support the pilot program
- Establish partnership in the vehicle, operations, and logistic
- Prototype vehicle and system testing & demonstration
- Pilot deployment and trial operations
- Expand operating envelops and missions

The actual timeline would depend on the industry progress, certification, and end-users/government agencies' collaboration, as with the other use-cases. However, last-mile aerial delivery operations are likely the earliest implemented use-case in the report. Since the missions are unmanned in nature, the passenger safety requirements and provisions are not part of the equation. As there are many last-mile logistic missions one can envision, we can easily assign several trial operations representing meaningful missions and real-world capability requirements. It is also much easier to transform from trail tests to regular operations in a shorter time than manned missions. Simplified remote piloting and semi/full autonomy capabilities would maximize mission effectiveness and likely the focus on early testing. Based on the eVTOL and UAS industry progress to date, initial trial missions could start as early as 2022-2023, while expanded implementation is likely to occur in the 2024-2025 timeframe.

Risks and Risk Mitigation

- **Technology integration and reliability.** eVTOL technology and air vehicle integration and operations are relatively new and uncertainties exist. The system should be deployed in an autonomous mode only for package delivery missions. eVTOL aircraft should be deployed first for missions in less populated areas and then expand the operations to broader areas. Military use for resupply missions would be an attractive early adoption for the technology.
- **Vehicle development and testing**. For developers, air vehicles will be based on their current platform but tailored for the package delivery with cargo pod or convertible interior. eVTOL safety assessment and redundancies built into their vehicle remain unchanged. Because the last-mile aerial delivery missions will not carry people, early test trail and deployment is achievable with reasonable system reliability assessment in place.
- **Inter-agency coordination and operations.** As this is a new capability that did not exist in the past it will take close coordination between OEMs, agencies and supporting operators to make it work as intended. Risks can be mitigated by careful planning, pre-deployment communications, training and education of the new system capabilities and the limitations and operations before actual deployment. Selection of missions and locations is also critical to ensure success.

Moving Forward

As identified in this white paper, eVTOL aircraft have the potential to transform future Public Services through a variety of applications. We believe that this future can only be materialized in collaboration with government agencies and stakeholders at the international level. As the world may face more frequent disasters and crises in the future, eVTOL aircraft may help mitigate their impact and offer new solutions to these problems. Important aspects of regulations, technologies, safety, procedures, and utilizations, specific to the use of eVTOLs for Public Services should be investigated. The democratization of eVTOL aircraft in Public Services missions such as disaster relief, search and rescue, law enforcement, and last-mile aerial delivery will only be possible if their integration with infrastructures is considered as early as possible. Planning, evaluations, trials may lead to early adoption in specific applications and pave the way towards more widespread adoption and implementations.

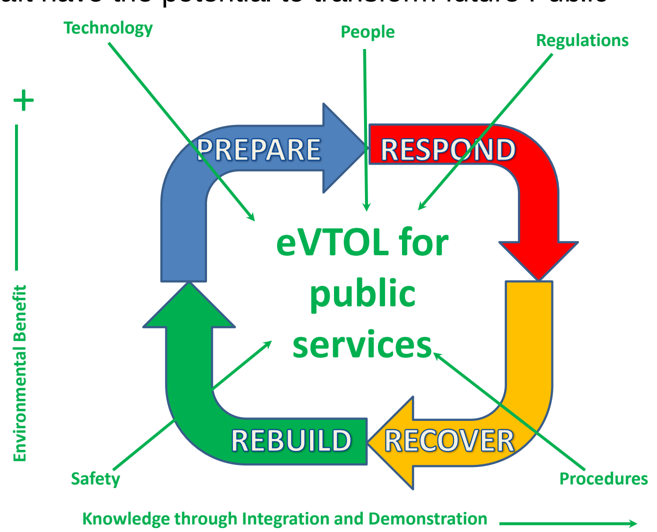


Figure 38. The core process for disaster management as applied to eVTOL public services. Figure courtesy of Marilena Pavel

Development and Test Roadmap

The general objective of this effort is to accelerate the use of eVTOL aircraft by identifying public use cases that may be deployed quickly and that could potentially allow gathering data and generating revenue sooner than commercial applications such as Urban Air Mobility. This may create a funding opportunity for OEMs and allow regulators to gather useful certification data under more closely managed operating theatres and potentially less risky use cases.

The purpose of this white paper is the following:

- Help decision makers, agencies, and operators responsible for the Public Services mission identified herein realize the potential opportunities that eVTOL aircraft represents;
- Allow stakeholders to identify and shortlist the most promising applications that would provide the best public return on investment;
- Identify near-term funding and demonstration opportunities to mature these concepts and define government (national or federal) initiatives that could be implemented in the next 6–24months to advance eVTOL aircraft in an effective way for the taxpayer.

There would be value in collecting the items shown in future work along with some of the items identified in the TVF roadmap so that there is a concise list that could be the basis for a broad area announcement posted to FedBizOpps (Federal Business Opportunities, FedBizOpps.gov is an internet data source about contracting opportunities and purchases the US government needs to make) i.e. soliciting RFIs/RFPs for a series of technologies and demonstrations that help mature these concepts.

Some non-exhaustive examples of specific technology developments and early operational demonstrations of eVTOLs that would benefit from near term (6 to 18 months) funding are:

- Demonstrations of small-scale deployments (e.g. water and fire-retardant deployment);
- Demonstrations of remotely piloted BVLOS and autonomous eVTOL flights;
- Demonstrations of collision avoidance systems during multi-aircraft operations;
- Development of fast-charging field stations and automated battery swapping solutions;
- Development of specific sensors (e.g. fire sensors, human life detection sensors);
- Development of standardized, modular and swappable payload attachments;
- Development of mobile communication systems (e.g. 5G) for autonomous operations of aircraft in remote or blacked-out locations;
- Development of advanced traffic management systems (e.g. UTM).

Future On-Demand Embedded eVTOL Public Services

Figure 39. Embedded on-demand logistics for public service missions, including natural disasters relief like Hurricane Harvey Houston flooding. Image courtesy of Johnny Doo

Current Public Services Agency aerial response capability is founded on the principle of dedicated resources. While standard air vehicles across civilian and military applications are often used for firefighting, Search and Rescue and disaster response, the actual asset is acquired and maintained by a specific fire department or Public Services agency. This includes dedicated pilots, aircrew and specialist technicians which requires high funding, high pilot and crew skill sets, extensive training requirements and dedicated facilities. Aircraft acquisition costs coupled with the crewing requirements make these a very specialist and limited service operating in a high-risk environment. As eVTOL aircraft become more frequently used in a civilian environment there is an opportunity to utilize this asset as a response capability to assist Public Services agency response. The opportunity exists to explore the use of civilian eVTOL aircraft for transport of rescue and response technicians in an aerial asset without the need for initial high acquisition and maintenance costs and dedicated crew. A core number of Public Services Agency eVTOL aircraft should be maintained, but the opportunity to access civilian aircraft or public transport systems such as those UBER is attempting to develop to meet surge requirements for sudden and rapid onset fire, emergency and disaster events are promising [ref. 62].

Aerial assets including helicopters require dedicated facilities such as airstrips and heliports. Emergency operations often require aircraft to travel long distances from the home base or operate remotely from an airstrip. In the case of helicopters, this requires fuel supplies at the forward staging area; the same logistic can work for the hybrid type of eVTOL fleet. At the same time, as all-electric eVTOL aircraft number grows, we will see the number and location of charging stations expand and becoming more commonplace. This increased recharging capability for sustained operations allows us to leverage the electric-only versions of the eVTOL aircraft as the fleet grows.

As the eVTOL system and related technology evolve, we can revolutionize the way we conduct our missions in a very different way than the way we operate ground and air assets today. For example, eVTOL aircraft can be deployed for firefighting. If and when small eVTOL aircraft are stationed at each and every fire station in the area, we will have the ability to quickly send out one or few eVTOLs to the location when the fire started. The effectiveness of fighting a fire quickly, and the ability to avoid it becoming a massive disaster based on the on-demand distributed network concept is significant. When needed, a fleet of eVTOL aircraft, even with limited payload capability for each unit, can operate in a carpet formation and put off or control a fire zone (such as a forest fire) with higher precision than traditional air vehicles. This capability can be enabled by the research and development advancements. For example, swarming technology was incorporated by the drone industry as demonstrated by the formation operation of hundreds of drones for Olympics or other events. The same unconventional thinking and mission method can be used for most other use cases already discussed in this white paper.

Figure 40. Swarm technology used in drones can be a game-changer in how we deploy the eVTOL fleet. Image courtesy of Marilena Pavel

This concept of operations would require minimal training and currency requirements for the rescue and response technicians in eVTOL aerial response operations which could be a familiarization course as opposed to intensive training. While this may seem like a major change in service and operations, it is natural progression with the introduction of new and capable technology. For example, several decades ago defibrillation devices were only located in hospitals and advanced care medical facilities; now they are commonplace in ambulances and even public spaces. This is an example of how technology can be applied to a broader use case. This is a similar concept of applying the new technology of eVTOLs capability as it develops to the broader fire and emergency services community.

Public Benefits

This paper identified selected applications of eVTOL aircraft for Public Services and their benefits. In addition to life-saving in natural and human-induced disasters, effective last-mile air mobility to help in disaster logistics, humanitarian add operations, firefighting, and supply delivery can significantly reduce financial losses and human casualties. The early deployment of the eVTOL system for Public Services has additional benefit for the industry development, economic and environmental benefits.

Potential Near-Term Benefits of Approach

Accelerated Certification

With Public Services applications leading the practical deployment of various eVTOL aircraft from mission-specific units to general purpose design, operating in various challenging conditions will provide solid certification experiences. Since eVTOL vehicles are a new type of aircraft design and the certification basis is still under development, practical operating experiences are critical to advance the regulatory processes and accelerate the overall eVTOL aircraft industry certification process and approval. As mentioned in reference 3, EASA has published the Special Condition for VTOL aircraft as the first step toward an anticipated standalone Certification Specification in the future. Industry groups such as the SAE

International Electric Aircraft Steering Group (EASG) strategically identifies, landscapes, and coordinates the various standardization activities necessary to support full-electric and more-electric aircraft applications at the top-level system, subsystem, and component levels. The EASG have identified gaps and have made recommendations to technical standards developing committees to revise or develop new standards. As a result, the recommendations have led to the creation of new standards for full electric, more electric, and hybrid-electric aircraft. Furthermore, new SAE International standards committees were launched to address the specific needs of electric aircraft and unmanned aircraft. These include:

- AE-7D Aircraft Energy Storage and Charging Committee
- E-40 Electrified Propulsion Committee
- G-32 Cyber Physical Systems Security Committee
- G-34, Artificial Intelligence in Aviation
- S-18UAS Autonomy Working Group

The American Society for Testing and Standards (ASTM) F44 General Aviation Committee, originally launched to develop new standards for Part 23 airplanes, also demonstrates interest in developing standards for eVTOL aircraft.

The ASTM F38 Unmanned Aircraft Systems Committee, which develops standards for small UAS under 55 pounds, also has new work items intended for larger UAS.

The American National Standards Institute (ANSI) UAS Standards Collaborative mission is to coordinate and accelerate the development of the standards and conformity assessment programs needed to facilitate the safe integration of UAS—commonly known as drones—into the national airspace system (NAS) of the United States. The aim is to describe the current and desired future standardization landscape, articulate standardization needs, drive coordinated standards activity, minimize duplication of effort, and inform resource allocation for standards participation. In December 2018, the Unmanned Aircraft Systems Standardization Collaborative (UASSC) has published a standardization roadmap, which identifies existing standards and standards in development, as well as related conformance programs, defines where gaps exist, and recommends additional work that is needed. The roadmap includes proposed timelines for completion of the work and lists organizations that potentially can perform the work. A revision of the Roadmap is currently in development and will be published in 2020. The UASSC itself does not develop standards.

Near-Term Revenue Generation

For OEM and system suppliers, the sooner we can establish use cases and go through the acquisition process to accelerate the trail and deployment the earlier the industry can start generating cash flow and revenue. The supporting industries of airspace management, navigation, infrastructure development, ground support equipment manufacturing, simulation and training, and specialty equipment manufacturing would experience increased revenue and future expansion and growth.

Improved Disaster Readiness

As discussed in the above use cases, and many other potential applications for Public Services, the use of eVTOLs can enhance our ability to prepare for and respond to various disaster situations. The newly enabled short- to mid-range vertical flight mobility is not intended to replace existing assets one to one, but rather add a different kind of capability and capacity to complement the existing operations in order to improve our disaster readiness. Over time, with large scale uses of general purpose eVTOLs worldwide and mission-specific platforms, will enable activating a portion of the fleet whenever and wherever needed to respond to disasters.

Cultural Acclimation to eVTOL aircraft

Sometimes new technologies are not widely accepted by the general public at the beginning. This learning curve associated with the technology and reserved public perceptions may slow the industry growth. Similarly, public acceptance challenges are expected with fully automated passenger cars. Public Services use of the eVTOL aircraft can make a difference especially when firefighters are rescued from unpredictable wildfire movement; food, water, and medicine delivered to the disaster area; or injured civilian lives are saved after major disaster. When people see eVTOL aircraft in action and serving the public interest, in an autonomous mode or with remote pilot, performing missions that positively impact lives, the cultural acclimation to eVTOL aircraft will accelerate. Nonprofit organizations such as the Community Air Mobility Initiative (CAMI) promote eVTOL aircraft to the communities and local level of government, providing education and resources to the public, decision makers, and the media.

Development of Industry Human Capital

By early trial tests, evaluations, and deployment, the Public Services missions can lead the development of the eVTOL industry human capital. The public use eVTOL aircraft have the same technology, development, qualification, production, and operations expertise required as the overall eVTOL industry but with some additional specialty equipment and operational challenges. Moving the Public Services sector forward would help generate the human capital needed for the eVTOL industry's long-term success.

Early use of 5G Communication

One of the key elements in managing disaster situations is communications. eVTOL aircraft for Public Services can be equipped with 5G technology for high-speed data communications for situation awareness and low latency transmission for real-time flight management including ability to deal with rapidly changing conditions and unauthorized drones in the operating area. Tethered eVTOLs can be operated from non-airport locations such as schoolyards and parking lots to act as an emergency 5G cell tower thus enable disaster relief and public communications in disaster areas.

Potential Long-term Benefits of Technology

Urban Transportation

This transportation architecture could reduce congestion for all commuters. For eVTOL aircraft users, their commute time could be used for work or relaxation instead of anxiously griping a steering wheel in stop and go traffic while looking for a way to reroute around an accident ahead. The traffic reduction by the deployment of the eVTOL system in urban areas can improve the driving experiences for even non-eVTOL users by reducing the total number of automobiles operating during the same period. It further allows the cities to accommodate population growth with the existing highway system. It could also increase safety by reducing "road rage," and minimizing the number of fatigued drivers on the roads. Additionally, given the significantly reduced vehicle volume, urban parking availability would increase significantly.

International Development

The World Bank estimates that half of the recent growth in Sub-Saharan Africa can be attributed to infrastructure investment [ref. 63]. Given the cost of roads and bridges and the complexity of working in some of these environments, eVTOL aircraft could create an opportunity for underdeveloped countries to skip a generation of infrastructure, forgoing vast investments in roads and bridges, for a more flexible, scalable, and less capital-intensive transportation system. The ability to use electricity generated solar power could make the implementation of an eVTOL aircraft infrastructure feasible without a need to invest in regional electric grids (note, solar energy density on the surface of the earth is 1 kW/m^2). Developing countries could purchase individual units as money becomes available for immediate incremental utility without having to wait on the completion of a complex multiyear concrete project to reap the benefits.

Regional Transportation

From a regional transport perspective, when looking at much of the single-aisle airline market, there is the potential to use eVTOL aircraft as a substitute under some circumstances. Given the time required to go to the airport, park, check baggage, go through security, actually fly, collect luggage and get ground transportation, often one finds that for a flight of one hour there is a required time commitment of four hours. If that one-hour flight is performed at 600 knots, it could be done by a 200 knot eVTOL aircraft in three hours of flight time (under near-term battery capacities this would entail a hybrid-electric system to achieve the intercity operations). For shorter flight distances (200–300 mile range) eVTOL aircraft offer a significant time saving over driving or today's commercial airline flights.

While certainly more data is necessary, it is plausible that eVTOL aircraft could potentially compete in price while potentially providing a more pleasant experience for the customer than the current commercial airline approach. All of this to suggest that former Airbus CEO, Tom Enders, might be wise when he says, "what if change is coming not from another country or company, but an entirely different industry" [ref. 64] and when he predicts that, "in a not too distant future, we'll use our smartphones to book a fully automated flying taxi that will land outside our front door—without any pilot." [ref. 65] While there is likely no risk that airlines will be competing against eVTOL operations anytime soon, in the long term, the potential for lower cost and less hassle alternative approaches for short to medium distance air travel for current airline transportation certainly exist. The airlines may eventually integrate eVTOL aircraft in their operating model to serve the feeder and short-range markets.

Reduced Carbon Emissions

As many of the eVTOL aircraft currently under development are electric only for short-range mobility they post no operational emissions. The source of the electricity for charging can derive from various sources, but the power generation system can move more toward solar, wind and other clean energy sources. At a minimum, localized emissions can be reduced for large cities with a massive number of cars running internal combustion engines like Denver, Beijing and other cities alike. For extended range capabilities, the hybrid-electric system is likely the near-term propulsion solution for eVTOL aircraft until batteries or other energy storage systems improve. The hybrid eVTOL system still offers emission advantages over conventional transportation in that it can turn off the engine or run it at idle, operate on electricity only mode during takeoff and landing. Engineering trade studies are currently underway to optimize the power scheduling of the hybrid electric propulsion modes. When the electrical generation is needed only at certain range and beyond, the engines will be operated at optimum constant rpm at peak efficiency with minimum emission. This operation also generates less noise and therefore is environmentally friendly.

Reduced Burden on Infrastructure

As the world is heading for rapid megacity expansion [ref. 66] the demand for infrastructure is proportionally challenging. Not only is the ground transportation system including cars, buses, and subway facing challenges to expand capacity due to limited land for highways and local roadways, but many of the existing subway systems are already at capacity. In addition, intercity transportation via airlines or interstate highways presents challenges in airport facilities, airspace congestion, highway expansion and maintenance budgets. A combination of different eVTOL aircraft range, from short-range urban transport, to short-to-mid-range intercity travel, can provide a solution to handle further growth of cities. The eVTOL aircraft can offer more energy-efficient, time-effective and environmentally more attractive solutions to rapidly expanding transportation infrastructure challenges. When air taxis are fully operational, there may actually serve to decrease population densities.

Advanced Manufacturing

To enable the large-scale deployment of eVTOL aircraft, cost-effective aviation quality manufacturing system and methodology are essential. Only when we can produce eVTOL units at a fraction of the cost of traditional helicopters of the same capacity, we will be able to take full benefits of the eVTOL offers. By leveraging the advanced manufacturing technology like additive manufacturing (3D printing), high-speed machining, advanced composites, and intelligent, flexible assembly lines, the promise of high quality yet cost-effective eVTOL aircraft manufacturing for production volume somewhere between low rate automotive production and the general aviation aircraft production rate can be realized.

Figure 41. Bell is thinking about the factory of the future needed to meet potential production rates of thousands of aircraft per year. Image courtesy of Bell

The efforts required for advancing the eVTOL manufacturing system would also benefit other industries including traditional aircraft and helicopter manufacturing as well as new generation electric cars that may share similar advanced electrical power systems.

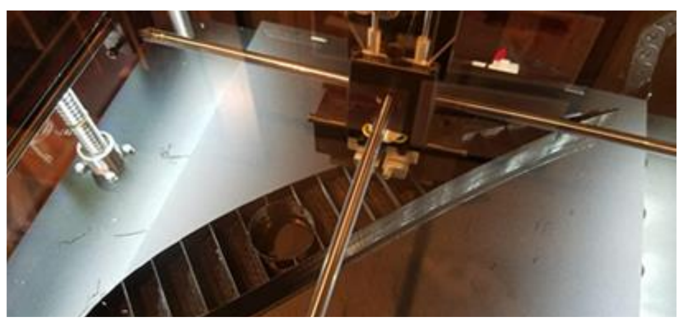


Figure 42. 3D printing of a wing airfoil section assembly with integrated structural elements by International Vehicle Research. Image courtesy of Johnny Doo

Acronyms/Abbreviations/Initialisms

A/A/I	Description	A/A/I	Description
3D	Three dimensional	ICP	Incident Command Post
5G	Fifth generation of wireless communications	IFR	Instrument Flight Rules
AC	Alternating Current	JAXA	Japan Aerospace Exploration Agency
AGL	Above Ground Level	L/D	Lift/Drag (ratio)
ANSI	American National Standards Institute	lb.	Pound (weight)
ASF	Aviation Sans Frontières	Li-Ion	Lithium-Ion (Battery)
ASTM	American Society for Testing and Standards	Li-Metal	Lithium-Metal
ATM	Air Traffic Management	Li-Sulphur	Lithium-Sulphur
BLDC	Brushless Direct Current (electric motors)	mph	Miles Per Hour
C2	Command and Control	NAS	National Airspace System
CAA	Civil Aviation Authorities	NENA	National Emergency Number Association
CAMI	Community Air Mobility Initiative	NGO	Non-Government Organization
CDC	Centre for Disaster Control and Prevention	NIOSH	National Institute for Occupational Safety and Health
CEO	Chief Executive Officer	NM	Nautical Miles
CFR	Code of Federal Regulations	OEM	Original Equipment Manufacturer
ConOps	Concept of Operations	PALS	Patient Air Lift Services
COTS	Commercial Off-the-Shelf	RCCI	Response for Concurrent Complex Incidents
CRED	Centre for Research on the Epidemiology of Disasters	RF-Saturated	Radio Frequency
DAA	Detect and Avoid	SAE	Formerly the Society of Automotive Engineers
DC	Direct Current	SAR	Search and Rescue
DEP	Distribute Electric Propulsion	STI	Scientific and Technical Information
DOC	Direct Operating Cost	sUAS	Small Unmanned Aircraft Systems
DoD	Department of Defense	TCCA	Transport Canada Civil Aviation
EASA	European Aviation Safety Agency	TVF4	Transformative Vertical Flight Working Group 4
EASG	Electric Aircraft Steering Group	UA	Unmanned Aircraft
EM-DAT	Emergency Events Database	UAM	Urban Air Mobility
EMS	Emergency Medical Services	UASSC	Unmanned Aircraft Systems Standardization Collaborative
eVTOL	Electric Vertical Take-Off and Landing		
FAA	Federal Aviation Administration	UAV	Unmanned Aircraft Vehicle
FedBizOps	Federal Business Opportunities	UN	United Nations
FEMA	Federal Emergency Management Agency	UNISDR	United Nations Office for Disaster Risk Reduction
FOD	Foreign Object Debris	US	United States
GIS	Geographic Information System	USD	United States Dollars
GO	Government Organization	USFS	United States Forest Service
HAA	Helicopter Air Ambulance	UTM	Urban Traffic Management (Airbus)
HAZMAT	Hazardous Materials	V2V	Vehicle to Vehicle
HEMS	Helicopter Emergency Medical Service	VFR	Visual Flight Rules
HIRF	High Energy Radio Frequency	VTOL	Vertical Takeoff and Landing
HITL	Human In The Loop	Wh/kg	Watt Hour per Kilogram
HOTL	Human On the Loop	WHO	World Health Organization
IATA	International Air Transport Association	XV-15	Bell tiltrotor VTOL

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