Emergency Response Ambulance Drones: Feasibility in Design for the GoAERO Challenge

Kilian Olen[1], Steven Willits[2], and Sebastian Scherer[2]

***Abstract*— This paper discusses the preliminary design of an electric vertical take-off and landing (eVTOL) ambulance drone, designed to address critical limitations in emergency response capabilities. Featuring a compact form factor and a robust suite of sensors, our proposed design offers a potential solution for navigating areas inaccessible to medevac helicopters, potentially aiding individuals in difficult-to-reach locations. This drone is currently being developed under the framework set by the HeroX GoAERO competition, a three-year effort challenging teams to create a safe, portable, and semi-autonomous aerial emergency vehicle. In this paper, we explore the design space for the vehicle, focusing on the sizing, weight distribution, power, and propulsion systems for the aircraft. While eVTOL passenger drones remain experimental, we leverage existing research and industry expertise to guide our design, aiming to offer a promising rescue solution that benefits from continued advancements in energy storage technologies.**

I. INTRODUCTION

A. *Motivation*

Emergency responders frequently encounter significant challenges in transporting people, supplies, and medical teams in and out of hazardous situations [1]. While a concerning increase in the amount of reported natural disasters can be attributed to improved reporting methods [2], these same improvements have allowed for shortcomings in emergency response capablilites to become readily apparent. Data from the Maine Rural Health Research Center identified an alarming statistic that nearly 4.5 million people across the continental United States lack access to rapid emergency medical services, with 52% of this impacted population residing in rural counties [3]. These “ambulance desserts", shown in Figure 1, demonstrate a concerning overlap with regions at high risk for natural disasters according to the Federal Emergency Management Agency (FEMA) Natural Risk Index, illustrated in Figure 2 [4].

This substantial gap in emergency response capabilities underscores the need for effective solutions to provide timely assistance. To address this need, major organizations such as NASA and AIAA have sponsored the HeroX GoAERO competition, a three-year initiative aimed at developing a safe, portable, and semi-autonomous aerial emergency vehicle. [5].

[1]Kilian Olen is with the Department of Aerospace Engineering and the Department of Physical Sciences, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, USA. olenk@my.erau.edu

[2]Steven Willits and Sebastian Scherer are with the Robotics Institute, Carnegie Mellon University, Pittsburgh, PA 15260, USA. swillits@andrew.cmu.edu, basti@andrew.cmu.edu

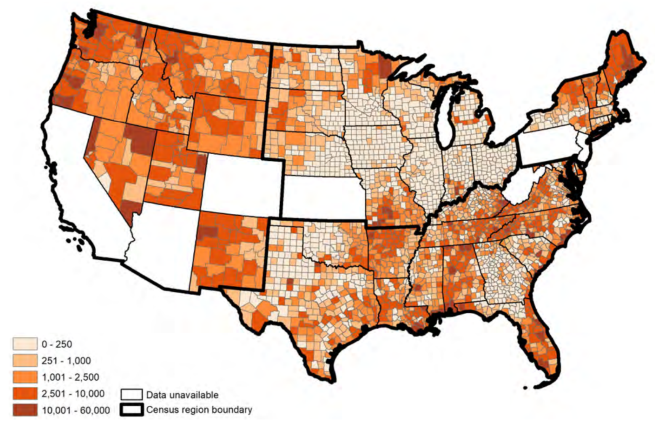

Fig. 1: Number of People Living in Ambulance Deserts by County, 2021-2022. Prominent impacted regions include the Appalachian region in the South, Western States with difficult mountainous terrain, coastal areas across the U.S., and the rural mountainous areas of Maine, Vermont, Oregon, and Washington [3].

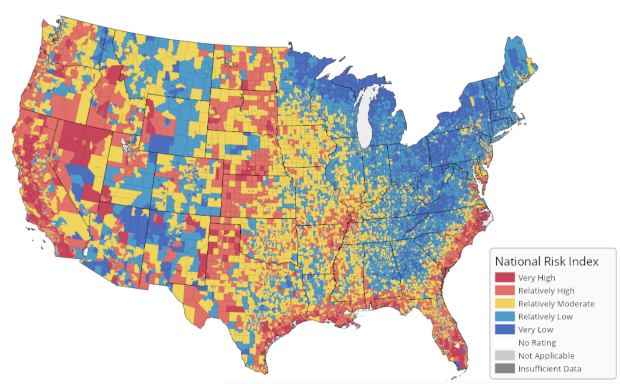

Fig. 2: FEMA National Risk Index, 2021. Scores provide comparisons between communities and hazard types largely based on historical data [4].

B. *Background*

Current aerial vehicles, such as medevac helicopters and planes, are effective for reaching areas inaccessible to ground transport vehicles. Unfortunately, the operation of aerial vehicles draws several limitations, including high operational costs, the need for large landing zones, and restricted access in extreme weather conditions or confined spaces [6]. These limitations can delay already time constrained emergency response times [7] and reduce the overall effectiveness of rescue operations.

The GoAERO competition aims to address these challenges by promoting electric solutions that leverage simplified components, smaller form factors, and reliable obstacle detection and avoidance technologies [5]. The developed vehicle will ultimately be tested in a series of 3 simulated missions to evaluate its field potential:

- Productivity Mission: Demonstrate the ability to quickly deploy the system and continuously ferry payload. (90 minutes)
- Adversity Mission: Demonstrate the ability to take off and land in difficult conditions. (30 minutes)
- Maneuvering Mission: Demonstrate the ability to tightly maneuver while avoiding obstacles. (20 minutes)

Details of these missions will be discussed as they pertain to the vehicle's design. For further information, refer to the GoAERO Fly-Off Rulebook [5].

C. Contribution

Existing literature covers the design of traditional rotorcraft [8,9] and recent advancements in general eVTOL conceptual design for urban air mobility [10-12]. While these studies address a range of scenarios, the GoAERO challenge introduces conditions that are particularly demanding for rotorcraft [13]. Given that the initiative is still in its early stages, this paper will not address sensing and control algorithms. Instead, it will focus on a major limitation that has hindered the practical application of electrification in aerial vehicles: Battery Energy Density.

Despite significant advancements in battery technology, which have made electric vehicles more viable [14], aerial vehicles face unique challenges. Any increase in vehicle weight necessitates a corresponding increase in lift and power consumption, complicating the use of electrical options due to its comparably low power to weight ratio. While several startups are in the process of developing eVTOL passenger drones, there remains a gap in their feasibility for high-risk situations like emergency response.

This paper will first explore key design parameters to meet the requirements of the HeroX GoAERO competition. It will then evaluate mass limits for these designs, which will inform the sizing equations for the aircraft. Finally, it will assess whether a sufficient power-to-weight ratio can be achieved to ensure an acceptable mission duration.

II. Preliminary Design

A. Sizing

We start by identifying the key setpoints for our system. Mission one involves transporting the drone via a flatbed truck, so our dimensions must comply with road regulations: a width of 8.6 ft (2.62 m), a height of 13.5 ft (4.11 m), and an overall length of 40 ft (12.19 m), though these limits can vary by state [15]. For context, our design is compared to existing medevac helicopters. The MD 500E, a light helicopter, has a height of 2.64 m, a fuselage width of 1.40 m, and a fuselage length of 7.28 m, with a rotor diameter of 8.05 m [16]. In contrast, the Sikorsky S76D, a more capable helicopter, has an overall height of 4.394 m, a fuselage width of 2.134 m, a fuselage length of 13.218 m, and a rotor diameter of 13.411 m [17].

To ensure the drone can efficiently operate in the field, we aim to keep its width within the range of these helicopters, though it can be extended up to 2.6 m if necessary. Similarly, the height is restricted to 2.3 m to fit into a standard 8 x 10 ft garage bay, but it can be extended to 4.1 m if needed. The length is influenced by the rotor size: two-bladed helicopters can transport their rotors along the flatbed, while multiblade rotors must be detached due to their tendency to extend beyond the flatbed limits. To avoid the need for field assembly, a dual-bladed rotor design is preferred. Alternatively, a multirotor design eliminates the need for a tail rotor, which reduces the overall length and allows for a more compact design by keeping all rotors near the fuselage. To maintain a reasonable trailer size, we designate the length of the vehicle to be less than 3.65 m.

Moreover, the dimensions and design choices directly impact the drones's operational versatility and logistical efficiency. By adhering to these size constraints and opting for a compact rotor design, the drone can be more easily integrated into various transportation and storage systems. This approach ensures that the drone is not only road-legal but also practical for deployment and storage. With these considerations in mind, the maximum physical design space for the vehicle is summarised below.

- Maximum length: 3.6 m (12 ft)
- Maximum Width: 2.6 m (8.5 ft)
- Maximum Height: 2.3 m (7.5 ft)

B. Mass

To estimate the mass of the aircraft, we first consider the electric motors. Due to the high costs of developing a vehicle of this size, we prioritize using materials that we have at hand. With this in mind, we will use twelve custom Safran Brushless Motors, each providing a continuous torque of 40.7 Nm, a peak torque of 100 Nm, a maximum RPM of 2300, a maximum temperature of 200°C, and a maximum voltage of 440 V. Each motor has a mass of 8.7 kg and will be mounted co-axially to optimize thrust while minimizing the vehicle's footprint.

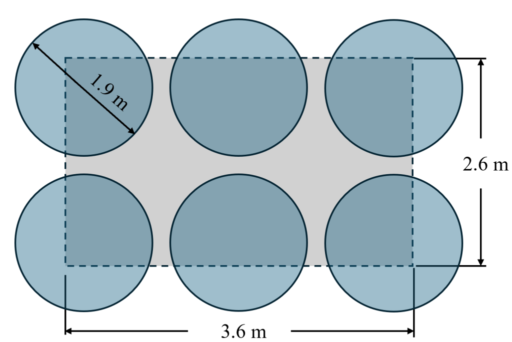

Fig. 3: Vehicle Footprint for the eVTOL Drone. Rotor placement allows easy alignment with legal road width limit.

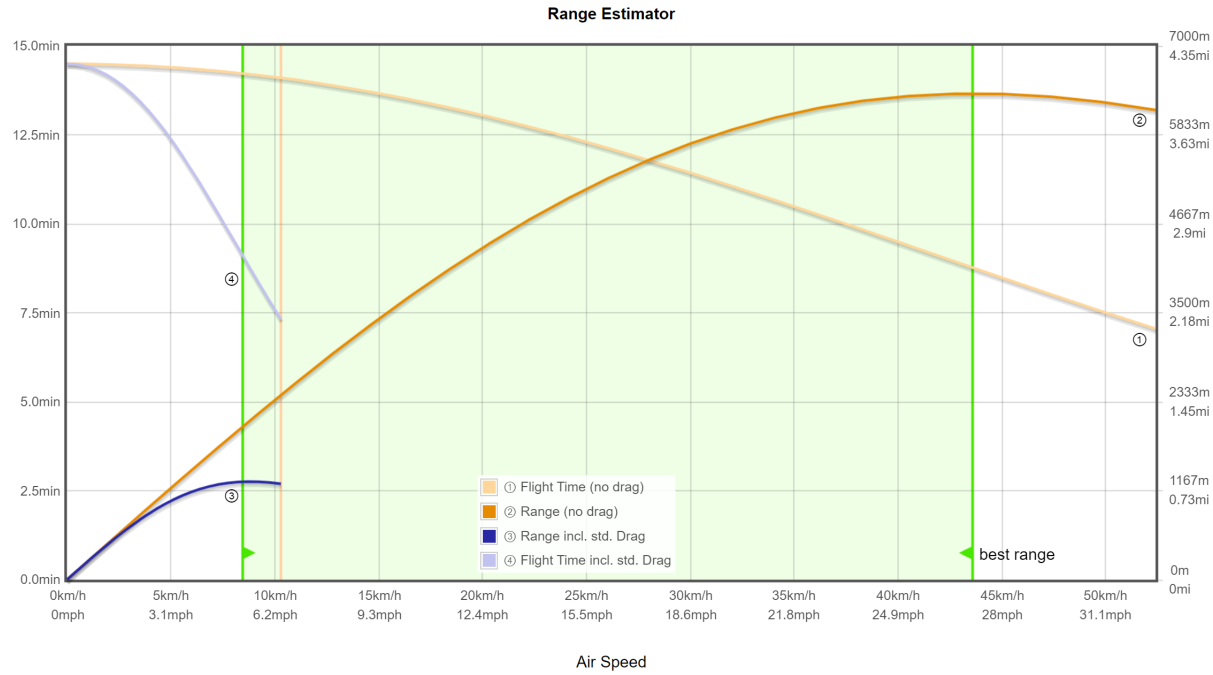

Fig. 4: Visualization of Drone Range and Flight Time. This example displays a maximum hover time of 14.6 minutes, with an estimated range of over 1 km. As the airspeed of the drone increases, performance dips nearly by half, rendering the aircraft incapable of performing maneuvering scenarios lasting 20 minutes.

The propellers are estimated using 35.5" carbon fiber blades from KDE [18], with each being 70 grams, totaling 140 grams per rotor. With twelve rotors, the total weight of the blades is 1.68 kg. Rotor shaft adapters, made from aluminum or steel, are estimated to weigh 100 grams each, summing up to 1.2 kg for all twelve adapters.

The aircraft will be equipped with twelve motor controllers, each handling a nominal voltage of 430 V and a maximum current of 49 A, producing up to 21 kW per motor. Assuming each electronic speed controller (ESC) weighs 60% of the motor's mass, each ESC is estimated to weigh 5.0 kg, totaling 59.3 kg for all twelve ESCs.

The high-voltage power leads connecting the ESCs and motors are estimated to total 120 ft in length, accounting for the distance to each motor and adding a 20% margin. Using 8 AWG 90-C wire, with a weight of 0.08 lbs/ft and an ampacity of 55 A, the total weight of the power cables is approximately 4.35 kg.

To power the motors, we propose using 2200 mAh LiPo cells with a nominal voltage of 3.7 V. Connecting 120 cells in series yields a nominal voltage of 444 V. For a two-pack system, the total battery mass is estimated at 114.24 kg. Including additional structural, sensing, and computing components, the estimated empty mass of the aircraft is approximately 400 kg, rounded to 451 kg (1000 lbs) to accommodate any additional components.

C. Power

To determine the power drain and maximum hover time, we used xcopterCalc [19], an online tool for estimating rotorcraft characteristics. By estimating the aircraft's total mass, including battery, motor system, structural components, sensors, and accessories, we can evaluate the effective flight time, range, and maximum payload capacity of the aircraft.

We adjusted the empty mass to explore how weight allocation affects payload capacity and whether adding an additional battery pack would be beneficial despite its added weight. We included a current drain of 10 A in our calculations to account for accessory sensors and computing power.

Testing with an empty mass of 450 kg provides a payload capacity of 170 kg, sufficient to carry the required 125 lb "Alex" Manikin. This configuration, however, limits the maximum hover time to just 11 minutes without payload. In contrast, an empty mass of 300 kg extends the hover time to 19.6 minutes, while an empty mass of 500 kg reduces hover time to 9.4 minutes. Testing with an 8-rotor system resulted in even shorter hover times and was therefore abandoned. Additionally, adding another battery pack slightly improved hover time by a few minutes at the cost of 57.12 kg, making it impractical. Detailed results are presented in Tables 1 & 2, which will be discussed in the following section.

TABLE I: Comparison of Empty Mass for a 12-rotor configuration

Empty Mass (kg)	300	350	400	450	500
Max Hover Time (min)	19.6	15.8	13.1	11.0	9.4
Max Payload (kg)	323	273	222	170	117
Max Tilt (deg)	61	56	50	43	36
Max Speed (km/h)	59	56	52	46	40
Max Range (m)	1591	1368	1195	1054	882
Max Climb Rate (m/s)	2.3	2.0	1.6	1.3	1.0
Rotor Failure Redundancy	Safe	Safe	Safe	Safe	Descend

TABLE II: Comparison of Empty Mass for a 8-rotor configuration

Empty Mass (kg)	300	350	400
Max Hover Time (min)	16.3	13.0	10.7
Max Payload (kg)	131	80	27
Max Tilt (deg)	46	36	21
Max Speed (km/h)	50	40	24
Max Range (m)	1611	1266	732
Max Climb Rate (m/s)	1.4	1.0	0.5
Rotor Failure Redundancy	Descend	Descend	Danger

III. Discussion

A. Feasibility

The GoAERO competition aims to develop an effective emergency vehicle that leverages advancements in electrical systems to maintain a compact size and showcase advanced sensing capabilities. Based on our analysis, the aircraft designed for this purpose would likely have an empty mass of approximately 451 kg (1000 lbs). Using data from the xcopterCalc toolbox, we found that even with a total mass of 300 kg (excluding payload), the system could not maintain hover for more than 20 minutes, which is the mission time limit for the maneuverability mission. This limitation impacts the ability to perform complex maneuvers and demanding tasks typical of emergency situations.

While the productivity mission is the longest of the three, lasting a total of 90 minutes, contestants are permitted to swap batteries multiple times throughout the challenge. Unfortunately, the feasibility of battery swaps is questionable if the drone cannot complete even one full loop with payload. Therefore, given the current design's limitations, we conclude that the proposed eVTOL design is not feasible for the GoAERO competition in its present configuration.

B. Recommendations

Despite significant advancements in battery technologies, current commercially available batteries are insufficient for solely powering an eVTOL ambulance drone, especially given the uncertainties associated with emergency response situations; However, with ongoing improvements, battery energy density may become adequate within the next few years. We encourage further exploration in this area to capitalize on these advancements.

For the GoAERO competition, we recommend exploring hybrid power sources to meet the mission requirements. A hybrid design would benefit from current battery advancements while addressing the power limitations of existing technologies. As battery technology progresses and the power-to-weight ratio reaches a sufficient level, a fully electric solution could become feasible.

IV. Conclusions

In this work, we examined the feasibility of an eVTOL ambulance drone within the framework of the HeroX GoAERO competition. We analyzed key design parameters, including sizing, weight distribution, and power systems, and evaluated the impact of varying mass on the drone's performance. Using the xcopterCalc tool, we tested various configurations and determined that current battery technology limits the maximum hover time and payload capacity, making a fully electric solution impractical for the competition's mission requirements.

Our findings highlight the challenges associated with developing an eVTOL ambulance drone using current commercially available batteries. While advancements in battery technology are promising, significant improvements in energy density are needed to achieve a viable fully electric design for emergency response scenarios.

Acknowledgment

This work is supported by the National Science Foundation under Grant No. 1950811 and sponsored by the AirLab at the Robotics Institute, Carnegie Mellon University, as a part of the Robotics Institute Summer Scholars (RISS) program. I would like to thank Steven Willits and the entire AirLab for their invaluable guidance throughout this process, as well as Rachel Burcin and Dr. John Dolan for their continued efforts in supporting aspiring researchers through the RISS program.

References

[1] Y. Jiang and Y. Yuan, "Emergency Logistics in a Large-Scale Disaster Context: Achievements and Challenges," International Journal of Environmental Research and Public Health, vol. 16, no. 5, Art. no. 5, Jan. 2019, doi: 10.3390/ijerph16050779.

[2] N. Joshi, R. Roberts, and A. Tryggvason, "Incompleteness of natural disaster data and its implications on the interpretation of trends," Environmental Hazards, vol. 0, no. 0, pp. 1–17, doi: 10.1080/17477891.2024.2377561.

[3] Y. Jonk, C. Milkowski, Z. Croll, and K. Pearson, "Ambulance Deserts: Geographic Disparities in the Provision of Ambulance Services [Chartbook]," Emergency Medical Services (EMS), May 2023, [Online]. Available: https://digitalcommons.usm.maine.edu/ems/16

[4] C. Zuzak, M. Mowrer, E. Goodenough, J. Burns, N. Ranalli, and J. Rozelle, "The national risk index: establishing a nationwide baseline for natural hazard risk in the US," Nat Hazards, vol. 114, no. 2, pp. 2331–2355, Nov. 2022, doi: 10.1007/s11069-022-05474-w.

[5] "GoAERO Prize | HeroX." Accessed: Aug. 06, 2024. [Online]. Available: https://www.herox.com/goaero

[6] T. C. Steenhoff, D. I. Siddiqui, and S. F. Zohn, "EMS Air Medical Transport," in StatPearls, Treasure Island (FL): StatPearls Publishing, 2024. Accessed: Aug. 06, 2024. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK482358/

[7] K. P. P. Abhilash and A. Sivanandan, "Early Management of Trauma: The Golden Hour," Current Medical Issues, vol. 18, no. 1, p. 36, Mar. 2020, doi: 10.4103/cmi.cmi_61_19.

[8] Leishman, J.G. Principles of Helicopter Aerodynamics, 2nd ed.; Cambridge University Press: New York, NY, USA, 2006.

[9] Prouty, R.W. Helicopter Performance, Stability, and Control; Robert, E., Ed.; Krieger Publishing Company: Malabar, FL, USA, 1990.

[10] O. Ugwueze, T. Statheros, N. Horri, M. Bromfield, and J. Simo, “An Efficient and Robust Sizing Method for eVTOL Aircraft Configurations in Conceptual Design,” Aerospace, vol. 10, p. 311, Mar. 2023, doi: 10.3390/aerospace10030311.

[11] A. Bacchini and E. Cestino, “Electric VTOL Configurations Comparison,” Aerospace, vol. 6, no. 3, Art. no. 3, Mar. 2019, doi: 10.3390/aerospace6030026.

[12] A. Bacchini and E. Cestino, “Key aspects of electric vertical take-off and landing conceptual design,” Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 234, no. 3, pp. 774–787, Mar. 2020, doi: 10.1177/0954410019884174.

[13] S. Conley et al., “VTOL Analysis for Emergency Response Applications (VAERA) - Identifying Technology Gaps for Wildfire Relief Rotorcraft Missions,” presented at the 6th Decennial VFS Aeromechanics Specialists’ Conference, Santa Clara, CA. Accessed: Aug. 06, 2024. [Online]. Available: https://ntrs.nasa.gov/citations/20240000476

[14] M. S. Ziegler and J. E. Trancik, “Re-examining rates of lithium-ion battery technology improvement and cost decline,” Energy Environ. Sci., vol. 14, no. 4, pp. 1635–1651, Apr. 2021, doi: 10.1039/D0EE02681F.

[15] [1] “Size and Weight Limitations,” PennDOT Driver & Vehicle Services. Accessed: Aug. 06, 2024. [Online]. Available: https://prddmv.pwpca.pa.gov:443/VEHICLE-SERVICES/Farm-Vehicles/Pages/Size-and-Weight-Limitations-for-Farm-Vehicles.aspx

[16] “MD 500E Specifications,” Light Helicopter Manufacturer | MD Helicopters. Accessed: Aug. 06, 2024. [Online]. Available: https://www.mdhelicopters.com/wp-content/uploads/2023/04/MD_500E_Product_Spec.pdf

[17] "Sikorsky S-76D Emergency Medical Services Helicopter," Lockheed Martin. Accessed: Aug. 06, 2024. [Online]. Available: https://www.lockheedmartin.com/content/dam/lockheed-martin/rms/documents/s-76/Sikorsky-S76D_EMS_Brochure.pdf

[18] [1] “KDE-CF355-DP Propeller Blades, 35.5" x 12.1, Dual-Edition Series (CW/CCW Set),” KDE Direct. Accessed: Aug. 06, 2024. [Online]. Available: https://www.kdedirect.com/products/kde-cf355-dp

[19] “eCalc - xcopterCalc - the most reliable Multicopter Calculator on the Web.” Accessed: Aug. 06, 2024. [Online]. Available: https://www.ecalc.ch/xcoptercalc.php