Future Energy
Open Access Journal
ISSN 2832-0328

May 2022| Volume 01 | Issue 01 | Pages 06-11

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.1.1.9

Future Publishing LLC

Review

Hydrogen fuel cell-powered drone ambulance for the emergency medical services

Ethan Taylor*, JJ Rivera

Department of Physical Science, Arkansas Tech University, 1701 N Boulder Ave, Russellville, AR, 72801, USA

ARTICLE INFO

Article history:
Received 20 February 2022
Received in revised form
19 March 2022
Accepted
22 March 2022

Keywords:
Drone, Ambulance, Hydrogen Fuel Cell

*Corresponding author
Email address: etaylor27@atu.edu

DOI: 10.55670/fpll.fuen.1.1.9

ABSTRACT

Many lives can be saved by defibrillation within the first minutes after sudden out-of-hospital cardiac arrest (OHCA). The main problem here is that the Emergency Medical Services (EMS) - even with the inclusion of other 'first responders' (police, fire brigade) - often do not arrive within the first critical 5–10 min after an OHCA. Further strengthening the survival network to ameliorate response time might impact outcome but is hampered by cost, lack of qualified workforce, and geography. Considering the yearly operational cost of a ground-based ambulance (including personnel, vehicle, materials, and overhead), the development of the survival network is expensive. Therefore, alternatives are required. In this context, using unmanned aerial vehicles (UAV) has been developed. However, the main problem here is that the traditional batteries powering the existing drones are not able to perfectly meet the flight time requirements in the drone ambulance missions because the energy density of the employed conventional batteries is extremely low. The hydrogen fuel cell (HFC) technology is showing to be a prominent source of power in the interest of increasing the flight time of UAVs, notably for its unrivaled efficiency and increasing popularity.

1. Introduction

The Unmanned Aerial Vehicle (UAV) or drone is becoming an increasingly popular tool for a wide range of applications. Though it may be traditional to think of drones as unmanned aircraft guided by either remote piloting or a system of onboard computers, this definition is too specific to truly encapsulate the broad history of the UAV. In fact, the concept of a drone dates back to 1849 when Austria utilized around 200 unmanned balloons filled with explosives during an attack on Venice [1]. The first concept of a multi-rotor aircraft, something much more akin to modern UAV's, was a quadcopter designed by Jaques and Louis Bréguet. They coined their creation the gyroplane. In 1916, however, the first true drone was built by British engineer Archibald Low, who also developed the radio guidance system [2]. Shortly afterward, the U.S developed the Kettering Bug, which was intended to be an "aerial torpedo" and used gyroscopic controls to detonate 82kg of explosives. The first reconnaissance drone was used during the Vietnam War, at which point drones also found new roles as decoys in combat and the medians through which psychological operations could undergo [3]. Furthermore, the 1960s also saw the first release of UAV technology to the public, in the form of remote-controlled (RC) planes. Between 1980 and 2010, drones saw major development in both the military and hobbyist sectors. In modern times, the drone is a booming technology with many uses by both the military and private sector, including photography, pipeline inspection, monitoring the climate, search and rescue, and delivery. One promising application of drones is the medical field, and more specifically, emergency response. These so-called ambulance drones were first proposed by the Delft University of Technology, which set out to respond to patients who required immediate medical attention by using a small UAV that delivered an automated external defibrillator (AED) to those in need [4]. Many lives can be saved by defibrillation within the first minutes after sudden out-of-hospital cardiac arrest (OHCA) [5]. The main problem here is that the Emergency Medical Services (EMS) - even with the inclusion of other 'first responders' (police, fire brigade) - often do not arrive within the first critical 5–10 min after an OHCA [6]. Further strengthening the survival network to ameliorate response time might impact outcome but is hampered by cost, lack of qualified workforce, and geography. Considering the yearly operational cost of a ground-based ambulance (including personnel, vehicle, materials, and overhead), the development of the survival network is expensive. Therefore, alternatives are required.

A drone ambulance would be helpful in situations where a typically manned ground ambulance cannot efficiently perform. In these situations, a drone ambulance would supplement the ground ambulance by providing lifesaving medication and supplies to the victims of medical emergencies until the ground ambulance arrived.

The means by which drones receive power is at the forefront of many issues surrounding their use in civilian sectors. Electrical means are deemed the most practical for a myriad of reasons including but not limited to safe storage and handling, lower noise relative to other means, and control and management, which cannot be provided by less precise means. While these benefits make electric batteries seem viable, the drawbacks of this solution are plentiful. Flight time and flight range are the two most important ones for analyzing the usage of UAV's in the medical sector. A study by Simic, Bil, and Vojisavljevic [7] attempted to find solutions to these specific downfalls of battery-powered UAV's. The paper mentions that simply increasing the size and, therefore, the capacity of the battery is not an option, as it would drastically affect the weight of the drone. Another option expressed in this study is the possibility of wireless energy transfer (WET) as a means of charging the drone. Though the data from the experiments with WET in the paper do show promise, no wide-scale test using power transmission lines have been conducted. The tests show the concept of WET-charged drones to be a real possibility, though admittedly not soon.

Though not a brand-new phenomenon, UAVs are just beginning to reach their true potential in terms of their utility. Active research is being done in the field, and genuine breakthroughs and innovations occur. In this context, the primary objective of this paper is to focus on the drone ambulances demonstrating the viability and the advantageous nature of HFCs as a method of supplying power to UAVs and how this alternate power supply is preferred in the case of an emergency response drone.

2. Ambulance response time

One of the most important aspects of UAVs when comparing them to traditional ground-based ambulances is response time. A study conducted by Blackwell and Kaufman [8] on the effectiveness of emergency response systems in an urban setting found a substantial cut-off time that results in a higher mortality rate. Namely, in cases where patients waited more than 5 minutes for emergency services, the average mortality rate experienced an increase of over 300%. To elaborate further on the benefit that an ambulance UAV would provide, a study by Poljak and Sternbenc [9] presents a case for the idea, specifically as it is related to response time. To test response time, a mathematical model was employed which analyzed drone delivery of AED's and compared it with historical response times for ambulances in eight regions in Canada. It was then found that for the average response time to be reduced by 3 minutes, 81 bases with a total of 100 drones would be needed. In addition to this, a pilot study was conducted in Stockholm, Sweden, using AED-equipped 8-rotor UAVs, which concluded that drone delivery of AEDs was faster in all 18 pilot cases. The average time that was saved in this study was 16.5 minutes [10]. That much time saved is incredibly valuable and lifesaving, especially in out-of-hospital cardiac arrest (OHCA) cases. Usage of an AED within 3-5 minutes of cardiac arrest results in survival rates as high as 50-70% [11]. Yet another study conducted in Stockholm, Sweden, gave remarkably similar results [12]. Based on their research, it was found that the time-sensitive case of OHCA often required much faster response times than a ground-based ambulance could reasonably provide. Stockholm presents an excellent case study for the utility of drone ambulances as it is made up of densely packed cities and stretched out archipelagos. It is also home to a plentiful number of OHCA cases a year. Based on the results of this study, the drone response time is faster in nearly all cases, no matter the drone launch point. What is even more remarkable is that the drone's response time is often within the five minutes needed for OHCA care.

The potential uses of a UAV system in healthcare are not strictly limited to ambulance-like emergency services. Drone programs have already been deployed and tested in countries where bacterial and viral infections threaten daily life. In Tanzania, for example, drones were able to provide much faster delivery times of vital medical supplies, which has helped combat its extremely high maternal mortality rate. Another potential usage of drones is the delivery of biological material. Early studies have shown that there is little to no risk of contamination or unusable samples as a result of drone flight, though more studies should be conducted.

Certain regions and areas provide a much greater need for a UAV ambulance system and provide a better environment for which to test them. One of these regions is more rural areas such as parks and mountains regions. Using a mathematical model figured below to determine flight time, it was found in a study by Wankmuller [13] that a UAV system in which drones are stationed at lodges and fire departments - as opposed to the more traditional hospitals - can provide emergency medical supplies with significantly faster speeds than that of a helicopter ambulance. The study even considered the usage of backup drones, a system in which two drones are assigned to each region of the overall area in question. If the drone closest to the patient is busy with another patient, the secondary drone is deployed. Even using the worst cases in which the secondary drone must be deployed, a scenario which is highly unlikely, the drone still can be sent to the patient and deliver the supplies in approximately 15% of the time it takes a helicopter. The particular interest of this study was AED delivery via drone. This is because of the high number of cardiac arrest cases in the region. As such, all the modeling of response time was made assuming the usage of a drone that could reasonably carry a portable AED.

Aside from the hazardous environment of a mountain, UAV ambulance systems need to be valuable and useful in more everyday environments as well. The study conducted by Kristensen, Ahsan, Mehmood, and Ahmed [14] sought to evaluate the efficacy of a UAV system by comparing the response time for a specific hypothetical traffic accident on a roundabout in Denmark. The roundabout they chose, as well the concept of a traffic accident, is a very useful tool in analyzing UAV ambulances. Traffic accidents are deadly and dangerous, and they require quick response times. The UAV statistics they used were from that of the Rescue Emergency Drone (RED), which is comparable to the DJI Phantom 4 in terms of carrying weight, flight altitude, and speed. This configuration was chosen as it was able to support the weight of an AED as well as a camera and compete with a ground-based ambulance in terms of response time. An AED in common conditions that occur because of traffic accidents can drastically improve the survival rate of the victims. In fact, when coupled with the nearly 200% faster response time from the drone, the survivability due to the AED goes up by 30%. The RED system proposed in this paper also mentions a system in which a bystander would be guided through the process of effectively using the AED. In addition to this, the proposed system would also include a camera that would allow medical personnel and first responders to gain invaluable insight into the scene before arrival. The system proposed by this pe authors would be the most comparable to the RED as it has been rigorously tested in terms of flight time, range, and most importantly, ability to adequately support the weight of medical supplies needed given the proposed system. This is, of course without mentioning the fact that the RED is a battery-powered UAV and, as such suffers from the flight speed, range, and payload weight problems listed above.

In terms of the usage of drones in natural disaster relief and response, D'Alessandro [15], mentioned the idea of UAVs as a system of surveillance rather than a direct emergency response like in many of the other papers discussed so far. In this case, drones are used to scout out areas in a much faster and cheaper fashion than traditional helicopters. The logistical benefits of using a drone to find survivors as well as to survey the damage to the surrounding environment and wildlife are extremely valuable to first responders on the scene as it allows them to fully assess the situation, a luxury not offered in time-sensitive situations. Drones can also reach lower altitudes than manned aerial vehicles and can do so much more safely. Night-time flight is also achievable with a UAV system. Time and resource mitigation are extremely important to disaster relief, with the survival rate taking a significant hit after the initial 3 hours and yet again after 72.

3. An Alternative to Current UAV Fuel Systems

As it currently stands, the Lithium-Polymer battery pack is the only alternative to the gas-powered UAVs used by the military, and LiPo batteries tend to only find use in the civilian sector by hobbyists. This is due to the extremely short flight time capabilities offered by LiPo technology, which is simply not enough for the types of operations the military would be conducting with their drones. As with any aircraft, the flight time of a battery-powered UAV is dependent on factors such as battery capacity, battery discharge, and average amp draw. A simple and easy formula to calculate the duration of a specific drone is: $T=CD/A\times 60$, where T is the Flight Time, C is the capacity of the Lithium-Polymer battery, D is the battery discharge, and A is the average amp draw [16]. Lithium-Polymer batteries are rather unique in that they require specialized care in order to maintain. They charge via a system referred to as CC/CV, which is an acronym for Constant Current/Constant Voltage. Essentially, this means that the battery keeps the charge rate constant until the battery is at its max voltage, at which point it will maintain that voltage while reducing the current. This is one of a few reasons why Lithium-Polymer batteries charge more slowly relative to, say, Nickel Metal-Hydride. The majority of Lithium-Polymer batteries charge at 1C, which is equal to 1× the capacity of the battery in amps.

It is for this reason that batteries are not a viable fuel system for use in the medical sector, seeing as how an ambulance UAV will be subjected to great distances for long periods of time while carrying a payload. However, a promising candidate as a viable alternative to gas and battery-powered UAVs is the fuel cell [17], which has seen major successes in the automotive industry. Developed in 2003 by Aerovironment and Lynntech [18], the first UAV to run on a fuel cell was named "The Hornet." It only achieved 5 minutes of flight time but set an astonishing precedent for future research into the efficacy of fuel cell technology, which has since made significant scientific leaps. One of the most important findings in the study conducted by Aerovironment and Lynntech was that the fuel cell did not alter the weight of the UAV at all, which means the efficiency of the fuel cell is not counteracted by its weight, and further emphasizes its viability as an alternative to gas and battery power.

An analysis conducted on fuel cell systems [19] shows that fuel cell technology is increasing in both popularity and usage, as fuel cells are more efficient than fossil fuels, have a higher energy density – which correlates to higher endurance, are relatively more reliable seeing as how they have less moving parts than traditional power sources, they are easy to implement, extremely quiet, have negligible emission, and could be used for much more than the UAV itself – with potential applications also being Auxiliary Power Systems and Ground Control Stations. Another exciting aspect of the fuel cell in the context of UAVs is the usage of a battery to power it. Current fuel cell systems seem to be hybrid by default, with the battery serving as a means of quick power meant to assist in starting flight and as a means of power redundancy in the event of fuel cell failure. This system is shown to be very effective in a study conducted by Yang et al. [20] where a propulsion system made of a homemade Fuel Cell and a Lithium-Polymer battery was developed for testing with Unmanned Aerial Systems. The homemade fuel cell stack was made of 36-cells, and a 3300-mAh 40C Lithium-Polymer battery was connected in parallel and only used for high-powered applications, such as take-off. The fuel cell stack ran on 99.9% pure Hydrogen and was regulated through a 2-step regulator. Hydrogen is used in fuel cells because it is the simplest element – consisting of only one proton and one electron – and it is an easily produced energy carrier.

The UAV was fixed-wing and made with larger wings to mimic a glider. This was done with long-term flight at low power in mind, and overall, the UAV weighed in at 21.19 kg, with the power system making up about 36.9% of the total weight. This setup provided a high fuel cell system efficiency of 45%, and the loss of the hydrogen was as little as 0.89%. Field test flights confirm the hybrid propulsion system to be an efficient and effective method of Unmanned Aerial Flight. A similar study was conducted in the search for alternatives to the use of fossil fuels to power aircraft in which the Korea Aerospace Research Institute (KARI) developed the EAV-2 [21], a middle-class unmanned aircraft that combined solar cell, fuel cell, and battery power. The EAV-2 was a low-speed, high endurance UAV capable of surveillance and ground observation. It could also fly autonomously. The study conducted served to analyze the data from a 22.13-hour test flight meant to understand the performance characteristics of each power source. The test took place in the Summer (doing so to take advantage of the solar cell), and the EAV-2 took off from the Goheung Space Center, Korea. During the flight, each power module provided a sense of redundancy by maintaining flight when the other sources of power failed (e.g. When the solar panels stopped working due to interference from cloud coverage). After 6:00 a.m., the solar cells became the primary power source for the aircraft, and during this time, the power available exceeded the power required, thus giving the battery an opportunity to charge and resulting in an increase in system voltage and an increase in fuel cell voltage to match the bus voltage. Prior to the test, power simulations were conducted to estimate the feasibility of each power system, and the simulation was compared to the actual flight, showing that the behavior of each power source could be predicted with accuracy. This study also emphasizes the capabilities of extended flight times using alternative energy sources as well as their environmental friendliness.

Regarding fuel source alternatives to the combustion engine or Lithium-Polymer batteries, it seems the proton exchange membrane (PEM) hydrogen fuel cell is the best candidate. Currently, there are six types of fuel cell systems according to the U.S Department of Energy [22], including the PEM fuel cell, but they are less than impressive when compared to the PEM fuel cell. The direct methanol fuel cell is powered by pure methanol and is usually used in portable applications such as cell phones and laptops. Alkaline fuel cells - although one of the first types of fuel cells developed by the U.S Space Program – are susceptible to CO_2 poisoning, which dramatically affects performance. Phosphoric acid fuel cells are usually less powerful than other fuel cells given the same weight and volume, and they are also much more expensive. Molten carbonate fuel cells (as well as solid oxide fuel cells) are relatively new types of fuel cell that operate at extremely high temperatures and are promising in performing the tasks which they are designed to complete. However, the very nature of these fuel cells makes them challenging to utilize in the context of UAVs. PEM fuel cells use a solid polymer as an electrolyte and carbon electrodes containing platinum, as well as hydrogen, oxygen, and water to generate power, and as a result, operate at relatively low temperatures, are more durable than other fuel cell types seeing as there are no moving parts and are simply more efficient at various weights and volumes.

A study was conducted on the design of a high-temperature proton exchange membrane (HT-PEM) fuel cell [23] used to power UAVs in high altitude missions – chosen because the use of PEM fuel cells above 10 km would best address issues both the internal combustion engines and low-temperature fuel cells would face in such harsh conditions. The UAV was manufactured by the Mediterranean of Aviation [Medavia. Ltd] and had a total airframe mass of 3 kg, a wing surface area of 0.8 m^2, and a total length of 1.6 m. The study successfully demonstrated not only the benefits of fuel cell technology in high altitude UAVs, but the benefits of high-temperature proton exchange membrane fuel cells in high altitude applications.

Chosun University in Korea conducted a study [24] in which they looked at a PEM fuel cell coupled with a metal-hydride storage tank to study the efficiency of a UAV powered by a fuel cell compared to a traditional Lithium-Polymer battery. An interesting point brought up in this study is the reason behind the inefficiency of battery power with small UAVs and the threats posed for the future of UAV usage. Battery-powered UAVs are inefficient power sources because the energy density in standard UAV batteries is approximately 200 w-hr/kg, whereas a minimum of 1,000 w-hr/kg is the type of efficiency the military requires for future missions. Assuming a compressed Hydrogen tank has only a 6% storage efficiency, the energy density of hydrogen fuel cells should exceed the minimum required 1,000 w-hr/kg efficiency. Furthermore, fuel cells have high thermal efficiency due to their use of electrochemical reactions as opposed to combustion reactions. To prove the efficiency fuel cells are estimated to provide, a fuel cell was designed. It consisted of two parts: A fuel stack and a hydrogen generator. The hydrogen was generated through a catalytic hydrolysis reaction from an aqueous (Sodium Borohydride) NaBH_4 solution and generated 200 W for 4 hours, which was three times more efficient than the standard UAV battery.

AeroVironment managed to fly their small Puma UAV for more than 9 hours using a fuel cell/battery hybrid system, Georgia Tech University, who, in 2006, launched a UAV powered by a 500 W fuel cell as one of the first projects undertaken by a university to study the benefits of fuel cell-powered UAVs, United Technologies Research Center [25], who developed the first fuel cell-powered rotorcraft, the Office of Naval Research [26], who achieved a world-record 23 hour and 17-minute fuel-cell powered flight, Cranfield University designed a small UAV of their own in which they could study the efficacy of Fuel Cell powered flight. The hydrogen system configuration consisted of a fuel cell, a battery connected in parallel, and a DC/DC converter to act as a voltage regulator for the fuel cell. The system consisted of three different modes: "Parallel," which allowed both the fuel cell and battery to connect to the drivetrain and both contribute stacking power, "Charging," which allowed for the battery to charge, and "Load Following," which is when only the fuel cell provided power for the system. Based on the results and load profiles, the hybrid system developed by Cranfield University using a 500 W PEM fuel cell and 8S battery was more than capable of powering a UAV during various phases of flight and allowed the fuel cell to operate at partial load range and constant output power, which maximized the stack efficiency.

Similarly, the Georgia Institute of Technology built the largest compressed hydrogen fuel cell-powered airplane [27], which featured a 500 W PEM fuel cell and hydrogen storage incorporated into the airframe. To maximize performance of the aircraft, the aerodynamic design was optimized by maximizing the propulsive efficiency and pushing the aircraft design towards a high-wing area and high aspect ratio. The wing was made of an SD-7032 airfoil with varying tapers and twists and was chosen as a compromise between high lift-to-drag ratio, high thickness-ratio, and excellent stall characteristics. Improved lifting surface efficiency compensated for the weight penalty brought with the weight of the fuel cell system. The aircraft was constructed of a 6061-T6 aluminum frame, the fuselage was a non-structural fairing of fiberglass, and the landing gear was constructed out of 6061-T4 aluminum. The flight test was divided into taxiing for 27 s, climbing for 45 s, descending for 38 s, and landing for the 50s. The results of testing demonstrated the feasibility of the fuel cell as a power source for UAVs, as the aircraft was capable of high power acceleration and steady cruise flight. Furthermore, at a constant tank size, the endurance of the aircraft was limited by the efficiency of the propulsion system, which means that by reducing the losses or improving the efficiency of the propulsion system, the performance of the aircraft can be improved. The results of this study are very promising regarding the use of hydrogen fuel cells as alternatives to simple battery-powered UAVs.

To further emphasize the importance of fuel cell development, one can simply look at the massive flight times reached by many fuel cell-powered UAVs. So far, many of the previously mentioned studies modeled and analyzed the efficiency of fuel cell-powered UAVs, but either did not attempt to push the UAVs to their maximum flight time, utilized extra power sources such as solar panels or did so in accordance with the technology at the time, reaching impressive - but still relatively short - times for the date at which they flew. However, many studies that successfully maximized UAV flight time with fuel cells yielded extremely impressive results. For example, the Department of Mechanical Engineering at Colorado State University – inspired by the Office of Naval Research's "Ion Tiger" -

developed and flew a UAV [28] powered by two 300 W PEM Fuel Cell stacks from Horizon Energy Systems capable of a 24-hour flight, while also developing a conceptual design that showed 28-hour flight to be feasible. However, despite the impressive feats of UAV endurance that fuel cells offer, it is largely unnecessary to sustain an ambulance UAV for 28 hours on end, but the motive behind reviewing so many papers that boast the ever-increasing flight time and efficiency of fuel cell-powered UAVs is to truly emphasize the importance fuel cells will play in the role of ambulance UAVs.

It is also worth considering what was only briefly touched on in this paper, which is the usage of drones for disease relief. This is incredibly pertinent now in 2020 as COVID-19 is still very much a worldwide pandemic. As stated in the body of this work, the usage of drones for the transport of biological material is not well studied but should be studied further. Most of the studies that were done happened in the midst and aftermath of the Ebola epidemic, particularly in developing countries. The consensus seemed that drones as a means for combating infectious diseases could be one of several tools necessary for the task. In general, the system proposed here is advantageous as both a drone and as a means of emergency response. The use of a hydrogen fuel cell allows for much greater flight time, range, and payload weight capabilities than a comparable drone using batteries. In addition, drones can reach areas unavailable to the traditional ground or air ambulances and do so unmanned. In general, drones are also quicker than conventional ambulances by a noticeable margin. The drone outlined in this paper is able to outperform a ground ambulance and do so for considerably cheaper than the lower-end price of $120,000 for an ambulance.

4. Conclusion

Though relatively new in practice, the concept and research on both hydrogen fuel cell UAVs as well as UAVs for medical usage is plentiful and strong, although research is on the independent topics and not on the combined topic of Fuel Cell Powered Ambulance UAVs. A plethora of studies shows that the hydrogen fuel cell is a more efficient means of fuelling a UAV than traditional electric batteries or combustion engines. In general, the usage of the fuel cell also provides enough power to overcome the added weight to the system, which is directly superior to electric batteries - as to increase the power output, one would need a considerable number of batteries which drastically alters weight and thus affects factors such as flight speed, time, and maneuverability. As for the usage of UAV's in the medical field, the most promising aspect of this is in the delivery of AEDs. In terms of the direct effect on survivability, response time affects out-of-hospital cardiac arrest victims far more than other emergencies which would require first-responders. Furthermore, a drone delivery system is by no means a new concept, and it is for this reason that an AED delivery drone is such a promising idea, as arguably one of the drones most common usages is that of delivery. Both in the private and public sectors, drones are useful tools for package deployment, which leads to plentiful research and development for drones that are specifically designed to deliver in a timely, safe, and efficient manner. The modification of these pre-existing designs to suit the delivery of an AED is well within reach. In addition to flight speed and the ability to fly in areas that would not be possible for an air ambulance, one large benefit is the unmanned nature of UAV's. This is a decidedly important factor as it allows for a safer and more diligent search and survey of emergency response scenes.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The author declares no potential conflict of interest.

References

[1] Prisacariu V. The History and the Evolution of UAVs from the Beginning till the 70s. J Def Resour Manag 2017;8:181–9.

[2] Saraoğlu M, Janschek K, Morozov A, Söylemez MT. Quadrotor Angle Stabilization using Full State Feedback by Partial Robust Pole Assignment Method: Pole Retention. Proc. 21st Int. Work. Comput. Sci. Inf. Technol. (CSIT 2019), Atlantis Press; 2019, p. 184–90. https://doi.org/10.2991/CSIT-19.2019.32.

[3] Mátyás P, Máté N. Brief History of UAV Development. Repüléstudományi Közlemények 2019;31:155–166–155–166. https://doi.org/10.32560/RK.2019.1.13.

[4] Van de Voorde P, Gautama S, Momont A, Ionescu CM, De Paepe P, Fraeyman N. The drone ambulance [A-UAS]: golden bullet or just a blank? Resuscitation 2017;116:46–8. https://doi.org/10.1016/j.resuscitation.2017.04.037.

[5] Hasselqvist-Ax I, Riva G, Herlitz J, Rosenqvist M, Hollenberg J, Nordberg P, et al. Early Cardiopulmonary Resuscitation in Out-of-Hospital Cardiac Arrest. N Engl J Med 2015;372:2307–15. https://doi.org/10.1056/NEJMoa1405796.

[6] Ringh M, Jonsson M, Nordberg P, Fredman D, Hasselqvist-Ax I, Håkansson F, et al. Survival after Public Access Defibrillation in Stockholm, Sweden - A striking success. Resuscitation 2015;91:1–7. https://doi.org/10.1016/j.resuscitation.2015.02.032.

[7] Simic M, Bil C, Vojisavljevic V. Investigation in Wireless Power Transmission for UAV Charging. Procedia Comput Sci 2015;60:1846–55. https://doi.org/10.1016/J.PROCS.2015.08.295.

[8] Blackwell TH, Kaufman JS. Response Time Effectiveness:Comparison of Response Time and Survival in an Urban Emergency Medical Services System. Acad Emerg Med 2002;9:288–95. https://doi.org/10.1197/AEMJ.9.4.288.

[9] Poljak M, Šterbenc A. Use of drones in clinical microbiology and infectious diseases: current status, challenges and barriers. Clin Microbiol Infect 2020;26:425–30. https://doi.org/10.1016/J.CMI.2019.09.014.

[10] Claesson A, Bäckman A, Ringh RNM, Svensson L, Nordberg P, Djärv T, et al. Time to Delivery of an Automated External Defibrillator Using a Drone for Simulated Out-of-Hospital Cardiac Arrests vs Emergency Medical Services. JAMA 2017;317:2332–4. https://doi.org/10.1001/JAMA.2017.3957.

[11] Perkins GD, Handley AJ, Koster RW, Castrén M, Smyth MA, Olasveengen T, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 2.

Adult basic life support and automated external defibrillation. Resuscitation 2015;95:81–99. https://doi.org/10.1016/J.RESUSCITATION.2015.07.015.
[12] Lennartsson J. Strategic Placement of Ambulance Drones for Delivering Defibrillators to Out of Hospital Cardiac Arrest Victims 2015.
[13] Wankmüller C, Truden C, Korzen C, Hungerländer P, Kolesnik E, Reiner G. Optimal allocation of defibrillator drones in mountainous regions. OR Spectr 2020;42:785–814. https://doi.org/10.1007/S00291-020-00575-Z/FIGURES/8.
[14] Rescue Emergency Drone for Fast Response to Medical Emergencies Due to Traffic Accidents n.d. https://publications.waset.org/10008200/rescue-emergency-drone-for-fast-response-to-medical-emergencies-due-to-traffic-accidents (accessed March 20, 2022).
[15] Drones:New Tools for Natural Risk Mitigation and Disaster Response | Semantic Scholar n.d. https://www.semanticscholar.org/paper/Drones%3ANew-Tools-for-Natural-Risk-Mitigation-and-Antonino/e7d231f8d17651f26bfc4011811bba7a2f299c4e (accessed March 20, 2022).
[16] Quadcopter flight time: How to calculate? | Flite Test n.d. https://www.flitetest.com/articles/quadcopter-flight-time-calculator-how-to (accessed March 20, 2022).
[17] Pan ZF, An L, Wen CY. Recent advances in fuel cells based propulsion systems for unmanned aerial vehicles. Appl Energy 2019;240:473–85. https://doi.org/10.1016/J.APENERGY.2019.02.079.
[18] Zhou M, Prasad JVR. Transient Characteristics of a Fuel Cell Powered UAV Propulsion System. J Intell Robot Syst 2013 741 2013;74:209–20. https://doi.org/10.1007/S10846-013-9903-X.
[19] González-Espasandín Ó, Leo TJ, Navarro-Arévalo E. Fuel cells: A real option for unmanned aerial vehicles propulsion. Sci World J 2014;2014. https://doi.org/10.1155/2014/497642.
[20] Yang C, Moon S, Kim Y. A fuel cell/battery hybrid power system for an unmanned aerial vehicle. J Mech Sci Technol 2016 305 2016;30:2379–85. https://doi.org/10.1007/S12206-016-0448-3.
[21] Lee B, Park P, Kim K, Kwon S. The flight test and power simulations of an UAV powered by solar cells, a fuel cell and batteries. J Mech Sci Technol 2014 281 2014;28:399–405. https://doi.org/10.1007/S12206-013-0936-7.
[22] Types of Fuel Cells | Department of Energy n.d. https://www.energy.gov/eere/fuelcells/types-fuel-cells (accessed March 20, 2022).
[23] Renau J, Barroso J, Lozano A, Nueno A, Sánchez F, Martín J, et al. Design and manufacture of a high-temperature PEMFC and its cooling system to power a lightweight UAV for a high altitude mission. Int J Hydrogen Energy 2016;41:19702–12. https://doi.org/10.1016/J.IJHYDENE.2015.12.209.
[24] Kim J, Kim T. Compact PEM fuel cell system combined with all-in-one hydrogen generator using chemical hydride as a hydrogen source. Appl Energy 2015;160:945–53. https://doi.org/10.1016/J.APENERGY.2015.03.084.
[25] Savvaris A, Xie Y, Malandrakis K, Lopez M, Tsourdos A. Development of a fuel cell hybrid-powered unmanned aerial vehicle. 24th Mediterr Conf Control Autom MED 2016 2016:1242–7. https://doi.org/10.1109/MED.2016.7536038.
[26] Laboratory for Autonomous Systems Research n.d. https://www.nrl.navy.mil/lasr/content/ion-tiger-fuel-cell-powered-uav/ (accessed March 20, 2022).
[27] Bradley TH, Moffitt BA, Mavris DN, Parekh DE. Development and experimental characterization of a fuel cell powered aircraft. J Power Sources 2007;171:793–801. https://doi.org/10.1016/J.JPOWSOUR.2007.06.215.
[28] Rhoads GD, Wagner NA, Taylor BJ, Keen DB, Bradley TH. Design and flight test results for a 24 hour fuel cell unmanned aerial vehicle. 8th Annu Int Energy Convers Eng Conf 2010. https://doi.org/10.2514/6.2010-6690.