The Energy and Autonomy Deficit: Barriers to Fielding Large Logistics UAS

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***Abstract*—Uncrewed Aerial Systems (UAS) have long been explored for logistics. While a number of systems offering small-payloads in commercial drone delivery and in military contexts have seen operational use, large-scale logistics UAS have yet to be adopted. A range of setbacks causes this, including technological and operational challenges that hinder the adoption of large logistics UAS. Here, we evaluate these challenges from a conceptual modelling perspective and forecast their applicability once these barriers are overcome. The study utilises technology trend modelling and activity mapping methodologies to predict the applicability of specific technologies that are currently identified to be operational challenges. Specifically, we model trends in technological improvements of the battery technology and aircraft control, and project its focus on landing zone autonomy and powertrain. The prediction illustration will focus on the current state of hybrid power and higher levels of automation as required for landing zone operations, and their development towards full autonomy. These models are validated through case studies of small commercial delivery drones and then applied to assess the feasibility and constraints of larger logistics UAS. Our analysis reveals that while small logistics UAS have been successfully integrated into operations, key technologies required for large-scale logistics UAS have yet to build-up a critical mass of research activity, particularly on landing zone autonomy and powertrain. Moreover, additional constraints beyond technological and operational challenges could include limitations in autonomy, certification hurdles, regulatory complexity, and the need for social and customer trust and acceptance.**

Keywords - Logistics UAS: autonomous drones: airspace regulation: drone certification.

I. INTRODUCTION

Logistics uncrewed aerial systems (UAS) have been in development for over six decades, at small and large scale [1]-[5]. Their business case is sound: reduced human intervention, timely delivery, efficiency, improved safety, automating supply chain, reducing cost, etc. And their impact will be profound once the technology scales.

At the small-scale end of uncrewed logistics aircraft, there are several historical examples of commercial success. In 2013, the multinational logistics company, DHL, delivered medicine using their Parcelcopter [6]. In short succession, a range of other examples followed, such as Google Wing, Amazon Prime Air and Zipline [7], with all three commencing initial operations in the period 2014 to 2016.

The success of fleets of these small parcel delivery was predicated on the maturing of several technology areas, including the development of more powerful and lighter lithium-ion batteries and solving the battery charging optimisation problem in 2018 [8][9]. Moreover, in 2017, small parcel delivery adopted automated flight controls, including improved avionics, fly-by-wire systems and optimised vehicle routing [6][10]-[13]. On mechanics, Distributed Electric Propulsion (DEP) made use of multiple electric motors and rotors, allowing for more stable and efficient vertical flight [14]-[18]. These drones were also made of lightweight materials such as carbon-fibre and other composites.

To be applicable for large logistics UAS, however, these drones need to be scaled up in size and capability and this is dependent on the maturity of key technologies [19]. Evolution needs to occur across five technology sub-sets: (1) autonomous flight operations integrated with traditional air

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traffic (including detect and avoid (DAA) and sense and avoid (SAA) technologies); (2) autonomous landing zone operations (including sensing technologies for that role); (3) powertrain developments commensurate to scaling to large logistics roles (including hybrid-electric powerplants); and (4) regulation and certification; and (5) and social license and acceptance. These last two include the regulation of future autonomous weapons systems [20][21][22], their ethical considerations [23]-[27] and social acceptance by law-abiding countries. Social acceptance in this regard has a distinct dual-use flavour, as large logistics UAS are expected to be used for commercial purposes, such as automated flying taxis and air ambulances, both of which require the public to be happy to be carried in them.

To forecast the applicability of large logistics UAS, it is important to review and evaluate key challenges. Here, we assess technological improvements of the battery technology and aircraft control, and project its focus on landing zone autonomy and powertrain. Specifically, the prediction illustration will focus on the current state of hybrid power and higher levels of automation as required for landing zone operations, and their development towards full autonomy. The revolution of small parcel delivery drones remains instructive. Identifying these technologies and forecasting their future applicability requires understanding innovation trajectories over time. We examine drone technologies through literature review and literature mapping, industry engagement, and activity analysis. Thence, we discuss these key technologies and analyse how each technology has evolved, ultimately aiming to qualitatively discuss and better forecast the applicability of large logistics drones.

II. METHODOLOGY

The technologies that led to the emergence of successful business models for small parcel delivery UAS are products of academic and community bodies of knowledge developed over several decades. These systems are based on small UAS used for photography in commercial roles and reconnaissance in military roles scaled in the early 2000's, that could carry a small amount of additional payload. Role scaling led to the mainstream adoption of multi-rotor UAS in the photography and real estate industries and to broad adoption in military operations and could be used to transport other equipment like envelopes, thumb drives, life vests, signal flares, etc. These aircraft were enabled by the maturity of miniaturised flight controllers, the reliability of batteries, and appropriate bandwidth data links.

To bring small parcel delivery drones to maturity, the primary problems that needed to be solved were the vehicle routing problem [6][10]-[13] and Battery-Charger Problem [8][9]. The commercial adoption of parcel delivery drones occurred once these problems were solved. Since then, the rates of industrial development and evolution in parcel delivery drones have significantly increased and outpaced academic technical publications. To forecast the technology's readiness, it is essential to track recent and contemporary developments in the industry. In Australia, where drone technology developments and innovation are mature, industry engagement is a valid method for exploring, scrutinising, and validating industry claims and publications. Notably, one of the most advanced small parcel delivery services, Google's Wing, was pioneered in Australia; another delivery service, Swoop Aero, was also based in Australia; and the most utilised flight controller for experimental UAS, ArduPilot, is also Australian. Hence, we've engaged with domestic industry to validate technological readiness of parcel delivery drones.

In general, we employed literature reviews, facilitated by bibliometric tool *Litmaps*, industry engagement, and activity analysis to examine logistics drone technologies and inform the assessment of future technology developments. Contemporary bibliometric analysis enabled by tools such as *Litmaps* is less structured than traditional approaches. The LitMaps tool proposes boolean queries/search strings and executes them for the researcher in the background. It also automatically builds links to identify key seed papers. We have chosen to display the *Litmaps* maps presented chronologically along the x-axis and citation count along the y-axis. To illustrate the relevance of citation count, the circles also increase in size in proportion to their citation counts. The plots are not linear: *Litmaps* uses a logarithmic scale that optimises the format for reader presentation. For this research activity, the data extraction occurred over March to November 2025 and the principle data source for citation count was *Google Scholar*. Modelling the operational reality is achieved when academic/industry breakthroughs correlate with commercial adoption. We can define the Time to Operational Reality (TOR) as:

$$\mathbf{TOR = T(breakthrough) + Lag}$$

Where T(breakthrough) is the year a technology subset reaches a critical mass of high-impact citations and Lag is a heuristic of historical 'breakthrough-to-use' observed in analogues. The methodology incorporates scoring rules and thresholds that are binary (pass/fail) based on a validation threshold (a technology is 'ready' when it shows a breakthrough pattern and commercial activity indicates scaling) and an 'invisible' penalty where, if regulatory maturity is low, a penalty factor is applied that can extend the forecast by decades.

Using predominantly small parcel delivery drone technologies we first confirm the methodology approach, which will then be expanded to include key areas of large-scale logistics UAS. For this paper, the model assumes that the successful trajectory of small supply drones (sub-25 kg) is a direct analogue for large-scale systems (payload of 500+ kg), that scarce academic research in high-stakes areas like landing autonomy is due to industrial secrecy rather than a total lack of technical progress and that primary uncertainty stems from strategic competition, where commercial or military competition can accelerates investment, shortening the Lag. Conversely, profound regulatory lag remains the largest source of unpredictability.

III. ANALYSING LOGISTICS DRONE TECHNOLOGY READINESS

It is worth noting that small logistics UAS gained their social license and acceptance, not due to a technology or commercial milestone, but due to the global pandemic of 2020, which forced much of the world into accepting the benefits of small parcel delivery [28]-[31]. Thus, although not without contention, small parcel delivery has become a ubiquitous element of modern economics. Additionally, lightweight structural material for aircraft was pioneered in the 1980s, firstly by the military, and then by commercial airline manufacturers [32]-[35]: it was already a very mature technology field by the time that small logistics drones needed composite airframes. This section explores key technological and operational readiness of large logistics UAS.

A. Landing zone autonomy

Small, commercial parcel delivery drones undertake landing operations with Global Positioning System (GPS) for location and simple and cheap altitude sensors, predominantly developed by the automotive industry. They can be simple because most operations are undertaken to and from well surveyed, urban areas, and the delivery landing zone is prescribed to be a cleared, flat area, usually a rooftop, driveway or clear backyard. However, robust landing conditions need to be considered for full applicability of parcel delivery drones and military logistics drones could provide some guidance. In highly contested areas, GPS cannot be assured, and the landing zones are not necessarily known in advance of a mission and cannot be assured to be clear from vegetation or other obstructions. Nor can perception systems from autonomous ground vehicles, which have benefited from development since the 1970's [36]-[40] and can be connected to the Internet, be transplanted onto drones as these aircraft are very weight sensitive and need sensors tuned to much longer ranges than those of cars. As such, military logistics drone landing zone operations need to be highly automated or semi-autonomous and augmented by multi-sensor terrain profiling. The field is not yet mature despite there being a range of academic sources over the past two decades [41]-[48], as seen in Figure 1.

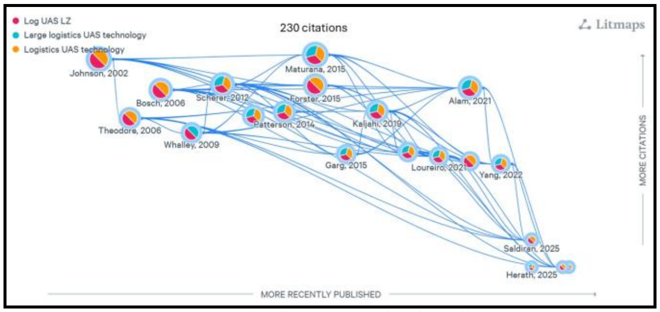

Figure 1. Logistics UAS landing zone technology literature mapping.

Our analysis reveals that publications are scarce and have a low impact, with the highest achieving only ~230 citations. None of the highest cited works show a citation pattern that indicates that they were 'breakthrough' research, as discussed by Faidi [49]. We surmise that there must be additional, unpublished research occurring within defence research institutions behind the curtains of security that cannot be accessed by open-source research, or as internal research and development within aerospace companies that is not being shared to retain ownership of the intellectual property of any breakthroughs. The motives for this are understood, but are noted as a likely significant cost factor compared to the more rapid development of this technology by a global research community.

Global, open-source research has been pointed out as a contributor to the successes of other autonomy technology developments over the past 20 years [16][50]-[53]. We should expect the development of landing zone autonomy for large logistics UAS to remain slow until the status quo changes. It is only with a significant, open, and prolonged investment in the development and integration of autonomy sensing systems that the challenges described above can be solved. Applying traditional, physical, and military acquisition approaches could mean it is not achieved until the 2030s at the earliest.

At a larger level, when considering whole of aircraft autonomy, it is noteworthy that the US Air Force, which is collaboratively prototyping with Joby Aviation a large, electric logistics and passenger aircraft, has not yet fully defined the Government Reference Architecture for Autonomy (A-GRA) [54]-[56] to which designers can design to. As of 2025, this is still in development. Thus, the journey towards fully autonomous large logistics aircraft still has a long way to go, as there remains a dearth of academic effort towards completing design reference architectures.

B. Powertrain

Batteries alone cannot power a large logistics drone across the distances that are needed to move large quantities of heavy parcels for commercial package delivery agencies, paying passengers for commercial taxi companies, patients for air ambulances, or combat supplies for the military. They just don't have the power density required [57]. For this reason a significant body of research has gone into hybrid-electric [58]-[60] and fuel cell [61]-[63] powerplants, with a considerable focus on hydrogen. Hydrogen provides distinct advantages of high power, long-range endurance, quieter operations and zero emissions, and enables the exploration of novel aircraft design concepts.

The focus on hydrogen is shared with and spun off from the automotive industry [64]-[66], and will need to consider the fundamental inputs to capability that will underpin that, such as generation, transportation, and storage infrastructure [67]. Field storage of hydrogen will be a particularly unique challenge for the military and may reduce the overall efficiency dividends presented by the military use of hydrogen as a fuel [68]-[72]. Our analysis shows that this is not a mature field, despite the range of academic sources over the past two decades, as seen in Figure 2.

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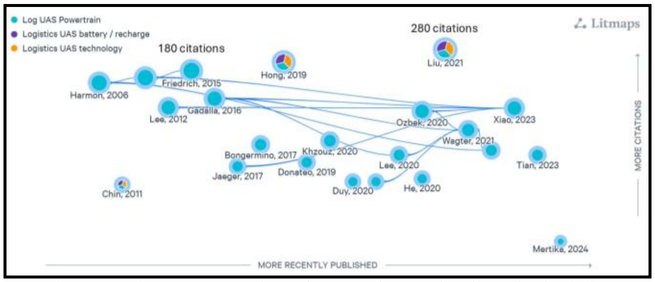

Figure 2. Literature mapping of powerplant technology for logistics uncrewed aerial systems.

Our analysis reveals that publications are scarce and have a low impact, with the highest achieving only ~280 citations on future battery chemistry to improve power density marginally (Liu, 2021), and the most impactful regarding hydrogen-powered aircraft, achieving only ~180 citations since 2015. None of the highest cited works show a citation pattern that indicates that they were 'breakthrough' research, as discussed by Faidi [49]. We surmise similar conclusions to our consideration of landing zone autonomy: that there must be additional, unpublished research within defence research institutions or internal research and development within aerospace companies that is not being shared to own the intellectual property of any breakthroughs. As such, we should expect hydrogen powerplant development for large logistics UAS to remain slow until the status quo changes. It is only with a significant, open and prolonged investment in the development and integration of these systems that the challenges described above can be solved. Applying traditional, physical and military acquisition approaches could see that not being achieved until the 2030s at the earliest, especially while significant technical challenges remain such as storage of liquid hydrogen, cryogenic management, lightening fuel cells, and thermal management of power electronics [73]-[77].

In the meantime, large logistics-like aircraft will exist, but they will be constrained to short distances on battery power only and will require the expense of a qualified pilot to be in the aircraft. If semi- or fully-autonomous large logistics drones are to succeed in a market breakthrough during a period of sustained strategic competition and conflict, significant profit could be generated, but may yet be years away, perhaps even decades. Poor awareness of technology maturity can lead to poor investment decisions and wasted money.

The case study of small parcel delivery drones in a commercial market, and on the recent application within the Ukrainian battlefield, illustrated the effectiveness of the methodology. The extension of that method to predict landing zone autonomy and powertrains capable of the ranges required for large logistics drones demonstrates the benefits.

IV. CONCLUSIONS

Our study has highlighted a distinct bifurcation in the developmental trajectory of logistics UAS. While small-scale logistics drones have achieved commercial viability and operational ubiquity, exemplified by the successes of Wing, Amazon Prime Air and Zipline, and their military counterparts, large-scale logistics UAS remain in a nascent, pre-commercial phase. By employing bibliometric analysis through Litmaps and validating trends against industry activities, this analysis package has demonstrated that the successful proliferation of small parcel delivery drones was predicated on the specific maturation of algorithmic solutions to the vehicle routing problem and the Battery-Charger Problem between 2014 and 2018. The correlation between high-impact academic literature and subsequent commercial adoption in the drone delivery sector serves as a validated heuristic for forecasting the readiness of larger systems.

Applying this methodology to large-scale logistic drones reveals a significant maturity gap. The analysis indicates that the critical technologies required to scale operations such as automated/autonomous landing zone sensing and high-endurance powertrains have not yet reached the 'breakthrough' levels of academic impact seen in earlier small-drone innovations. The scarcity of high-impact citations in these fields suggests that vital research is either stalling or, more likely, being sequestered within proprietary industrial silos or classified defence programs. The lack of open-source knowledge transfer acts as a brake on rapid innovation, preventing the wider industry from leveraging the collective problem-solving that propelled the small drone revolution. Consequently, the transition from retrofitted, expensive optionally piloted helicopters like the Unmanned K-MAX or U-Hawk to fully autonomous, purpose-built logistics platforms is unlikely to occur rapidly under the current development paradigm.

Ultimately, the future of large-scale logistics UAS will depend on a shift in acquisition and development strategies. It requires moving beyond the procurement of hardware and towards the co-development of certifiable autonomy architectures and the active sponsorship of regulatory frameworks. Until the 'invisible' barriers of regulation and the 'visible' barriers of power and sensing technologies are resolved in tandem, large-scale logistics drones will remain a niche capability rather than the revolution in military sustainment they promise to be. The timeline for widespread adoption is likely to stretch into the 2030s or beyond, requiring strategic patience and targeted investment in fundamental research rather than immediate procurement.

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REFERENCES

[1] L. R. Newcome, *Unmanned aviation: a brief history of unmanned aerial vehicles*. AIAA, 2004.
[2] J. E. Peters, S. Seong, A. Bower, H. Dogo, A. L. Martin, and C. G. Pernin, *Unmanned Aircraft systems for logistics applications*. Rand Corporation, 2011.
[3] K. Joyce, "Logistics support for unmanned systems," in *Operations research for unmanned systems*: John Wiley and Sons, 2016.

ISBN: 978-1-68558-356-9

[4] J. Choi, "#LOGBOTs – Making Army logistics “hard to find, hard to hit and hard to kill”," ed. Grounded Curiosity, 2018.

[5] Y. Li, M. Liu, and D. Jiang, "Application of unmanned aerial vehicles in logistics: a literature review," *Sustainability,* vol. 14, no. 21, p. 14473, 2022, doi: https://doi.org/10.3390/su142114473.

[6] A. Solomasov, "Analysis of supply chain operational performances using vehicle routing with UAV delivery in city logistics," Master en sciences de gestion, Université de Liège, Liège, Belgique, 2019.

[7] A. Jazairy, E. Persson, M. Brho, R. von Haartman, and P. Hilletofth, "Drones in last-mile delivery: A systematic literature review from a logistics management perspective," *The International Journal of Logistics Management,* vol. 36, no. 7, pp. 1-62, 2025.

[8] S. Park, L. Zhang, and S. Chakraborty, "Battery assignment and scheduling for drone delivery businesses," in *2017 IEEE/ACM International Symposium on Low Power Electronics and Design (ISLPED)*, 2017: IEEE, pp. 1-6.

[9] I. Hong, M. Kuby, and A. Murray, "A deviation flow refueling location model for continuous space: A commercial drone delivery system for urban areas," in *Advances in Geocomputation: Geocomputation 2015--The 13th International Conference*, 2017: Springer, pp. 125-132.

[10] C. C. Murray and A. G. Chu, "The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery," *Transportation Research Part C: Emerging Technologies,* vol. 54, pp. 86-109, 2015, doi: https://doi.org/10.1016/j.trc.2015.03.005.

[11] K. Dorling, J. Heinrichs, G. G. Messier, and S. Magierowski, "Vehicle routing problems for drone delivery," *IEEE Transactions on Systems, Man, and Cybernetics: Systems,* vol. 47, no. 1, pp. 70-85, 2016, doi: https://doi.org/10.1109/TSMC.2016.2582745.

[12] N. Agatz, P. Bouman, and M. Schmidt, "Optimization approaches for the traveling salesman problem with drone," *Transportation Science,* vol. 52, no. 4, pp. 965-981, 2018, doi: https://doi.org/10.1287/trsc.2017.0791.

[13] A. Otto, N. Agatz, J. Campbell, B. Golden, and E. Pesch, "Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey," *Networks,* vol. 72, no. 4, pp. 411-458, 2018, doi: https://doi.org/10.1002/net.21818.

[14] D. Mellinger and V. R. Kumar, "Minimum snap trajectory generation and control for quadrotors," *IEEE International Conference on Robotics and Automation,* 2011, doi: 10.1109/icra.2011.5980409.

[15] R. Mahony, V. Kumar, and P. Corke, "Multirotor aerial vehicles: Modeling, estimation, and control of quadrotor," *IEEE robotics & automation magazine,* vol. 19, no. 3, pp. 20-32, 2012, doi: https://doi.org/10.1109/MRA.2012.2206474.

[16] ArduPilot. "ArduPilot: Versatile, trusted, open." https://ardupilot.org/ (accessed 08 Jul 25.

[17] R. Pol and M. V. N. Aher, "Enhanced Drone Control With F4v3s Controller: A Technical Analysis," *European Chemical Bulletin,* vol. 12, no. Special Issue 4, 2023.

[18] Betaflight. "Betaflight: Pushing the limits of UAV performance." https://betaflight.com/ (accessed 05 Sep 25.

[19] K. Stepanenko, "The battlefield AI revolution is not here yet: The status of current Russian and Ukrainian AI drone efforts," ed: Institute for the Study of War, 2025, pp. https://understandingwar.org/backgrounder/battlefield-ai-revolution-not-here-yet-status-current-russian-and-ukrainian-ai-drone.

[20] J. Williams, "Locating LAWS: Lethal autonomous weapons, epistemic space, and “meaningful human” control," *Journal of Global Security Studies,* vol. 6, no. 4, p. ogab015, 2021, doi: https://doi.org/10.1093/jogss/ogab015.

[21] M. Homayounnejad, "Lethal autonomous weapon systems under the law of armed conflict," King's College London, 2019.

[22] D. Copeland, R. Liivoja, and L. Sanders, "The utility of weapons reviews in addressing concerns raised by autonomous weapon systems," *Journal of Conflict and Security Law,* vol. 28, no. 2, pp. 285-316, 2023, doi: https://doi.org/10.1093/jcsl/krac035.

[23] C. Hoyos, "Development of autonomous UAVs raises ethical questions," *The Financial Times,* pp. 3-3, 2013.

[24] S. K. Devitt and D. Copeland, "Australia's approach to AI governance in security and defence," in *The AI wave in defence innovation*: Routledge, 2023, pp. 217-250.

[25] E. H. Christie, A. Ertan, L. Adomaitis, and M. Klaus, "Regulating lethal autonomous weapon systems: exploring the challenges of explainability and traceability," *AI and Ethics,* vol. 4, no. 2, pp. 229-245, 2024.

[26] T. Hellström, "On the moral responsibility of military robots," *Ethics and information technology,* vol. 15, no. 2, pp. 99-107, 2013, doi: https://doi.org/10.1007/s10676-012-9301-2.

[27] C. Enemark, "A Code of Ethics for Drone Users. ," in *Air/Space Blog*, ed: ASPC, 2023.

[28] S. Melo, F. Silva, M. Abbasi, P. Ahani, and J. Macedo, "Public acceptance of the use of drones in city logistics: A citizen-centric perspective," *Sustainability,* vol. 15, no. 3, p. 2621, 2023, doi: https://doi.org/10.3390/su15032621.

[29] Z. Zhang, C.-Y. Xiao, and Z.-G. Zhang, "Analysis and empirical study of factors influencing urban residents’ acceptance of routine drone deliveries," *Sustainability,* vol. 15, no. 18, p. 13335, 2023, doi: https://doi.org/10.3390/su151813335.

[30] D. Zhang, P. P.-J. Yang, and J.-Y. Tsou, "Advancing Social Equity in Urban UAV Logistics: Insights from the Academic Literature and Social Media," *Drones,* vol. 8, no. 11, p. 688, 2024, doi: https://doi.org/10.3390/drones8110688.

[31] S. Schmidt and A. Saraceni, "Consumer acceptance of drone-based technology for last mile delivery," *Research in Transportation Economics,* vol. 103, p. 101404, 2024, doi: https://doi.org/10.1016/j.retrec.2023.101404.

[32] A. P. Mouritz, *Introduction to aerospace materials*. Elsevier, 2012.

[33] S. Pantelakis and K. Tserpes, *Revolutionizing aircraft materials and processes*. Springer, 2020.

[34] S. Kumar and N. P. Padture, "Materials in the aircraft industry," in *Metallurgical design and industry: Prehistory to the space age*: Springer, 2018, pp. 271-346.

[35] S. Anand and A. K. Mishra, "High-performance materials used for UAV manufacturing: Classified review," *International Journal of All Research Education and Scientific Methods,* vol. 10, no. 7, pp. 2811-2819, 2022.

[36] S. P, R. Gudla, V. Telidevulapalli, J. Kota, and G. Mandha, "Review on self-driving cars using neural network architectures," *World Journal of Advanced Research and Reviews,* vol. 16, pp. 736-746, 11/30 2022, doi: 10.30574/wjarr.2022.16.2.1240.

[37] F. Rosique, P. J. Navarro, C. Fernández, and A. Padilla, "A systematic review of perception system and simulators for autonomous vehicles research," *Sensors,* vol. 19, no. 3, p. 648, 2019.

[38] A. Townsend, "The 100-Year History of Self-Driving Cars: What the long history of the autonomous vehicle reveals about its fast-approaching future," ed. Medium, 2020.

[39] J. Lindsey, "Self-driving cars vs the world," *Popular Mechanics,* pp. 44-58, 2024.

[40] L. Jones, "Driverless when and cars: where?[automotive autonomous vehicles]," *Engineering & Technology,* vol. 12, no. 2, pp. 36-40, 2017.

[41] S. Scherer, L. Chamberlain, and S. Singh, "Autonomous landing at unprepared sites by a full-scale helicopter," *Robotics and Autonomous Systems,* vol. 60, no. 12, pp. 1545-1562, 2012, doi: https://doi.org/10.1016/j.robot.2012.09.004.

[42] F. Amzajerdian, D. Pierrottet, L. B. Petway, G. D. Hines, V. E. Roback, and R. A. Reisse, "Lidar sensors for autonomous landing and hazard avoidance," in *AIAA SPACE 2013 conference and exposition*, 2013, p. 5312.

[43] T. Patterson, S. McClean, P. Morrow, G. Parr, and C. Luo, "Timely autonomous identification of UAV safe landing zones," *Image and Vision Computing,* vol. 32, no. 9, pp. 568-578, 2014.

[44] D. Maturana and S. Scherer, "3d convolutional neural networks for landing zone detection from lidar," in *2015 IEEE international conference on robotics and automation (ICRA)*, 2015: IEEE, pp. 3471-3478, doi: https://doi.org/10.1109/ICRA.2015.7139679.

[45] M. A. Kaljahi *et al.*, "An automatic zone detection system for safe landing of UAVs," *Expert systems with applications,* vol. 122, pp. 319-333, 2019.

[46] V. Turan, E. Avşar, D. Asadi, and E. A. Aydın, "Image processing based autonomous landing zone detection for a multi-rotor drone in

emergency situations," *Turkish Journal of Engineering,* vol. 5, no. 4, pp. 193-200, 2021.

[47]M. S. Alam and J. Oluoch, "A survey of safe landing zone detection techniques for autonomous unmanned aerial vehicles (UAVs)," *Expert Systems with Applications,* vol. 179, p. 115091, 2021, doi: https://doi.org/10.1016/j.eswa.2021.115091.

[48]T.-T. Nguyen, V. Van Rijswijck, G. De Cubber, B. Janssens, and H. Bruyninckx, "State-of-the-art autonomous landing solutions for UAVs on moving platforms," in *Autonomous Systems for Security and Defence II*, 2025, vol. 13680: SPIE, pp. 129-168.

[49]S. Faidi, *Assessing Bibliometrics for the Automation of Technology Readiness Level Assessments*. University of Toronto (Canada), 2021.

[50]S. Baldi, D. Sun, X. Xia, G. Zhou, and D. Liu, "ArduPilot-based adaptive autopilot: Architecture and software-in-the-loop experiments," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 58, no. 5, pp. 4473-4485, 2022.

[51]FPV University, "How and why Betaflight was made? | From MultiWii to Betaflight and INAV," ed. YouTube, 2022.

[52]P. Burdziakowski, N. Razmjooy, V. Estrela, and J. Hemanath, "Open-source software (OSS) and hardware (OSH) in UAVs," 2020.

[53]D. Tezza and M. Andujar, "First-person view drones and the FPV pilot user experience," in *International Conference on Human-Computer Interaction*, 2022: Springer, pp. 404-417.

[54]J. Kauffman, "Reliable Robotics, U.S. Air Force collaborate on autonomy architecture," ed. Defense and Munitions, 2025.

[55]D. Taylor, "Collaborative Combat Aircraft autonomy architecture, air vehicle being developed separately, official says," ed. Military Embedded Systems, 2025.

[56]G. C. Allen and I. Goldston, "The Department of Defense's Collaborative Combat Aircraft Program: Good News, Bad News, and Unanswered Questions," ed. Center for Strategic and International Studies (CSIS), 2025.

[57]A. Townsend, I. N. Jiya, C. Martinson, D. Bessarabov, and R. Gouws, "A comprehensive review of energy sources for unmanned aerial vehicles, their shortfalls and opportunities for improvements," *Heliyon,* vol. 6, no. 11, 2020.

[58]M. Soleymani, V. Mostafavi, M. Hebert, S. Kelouwani, and L. Boulon, "Hydrogen propulsion systems for aircraft, a review on recent advances and ongoing challenges," *International Journal of Hydrogen Energy,* vol. 91, pp. 137-171, 2024.

[59]M. Dudek, P. Tomczyk, P. Wygonik, M. Korkosz, P. Bogusz, and B. Lis, "Hybrid fuel cell–battery system as a main power unit for small unmanned aerial vehicles (UAV)," *International journal of electrochemical science,* vol. 8, no. 6, pp. 8442-8463, 2013.

[60]C. Friedrich and P. A. Robertson, "Hybrid-electric propulsion for aircraft," *Journal of Aircraft,* vol. 52, no. 1, pp. 176-189, 2015.

[61]Ó. González-Espasandín, T. J. Leo, and E. Navarro-Arévalo, "Fuel cells: A real option for unmanned aerial vehicles propulsion," *The Scientific World Journal,* vol. 2014, no. 1, p. 497642, 2014.

[62]Z. Pan, L. An, and C. Wen, "Recent advances in fuel cells based propulsion systems for unmanned aerial vehicles," *Applied Energy,* vol. 240, pp. 473-485, 2019.

[63]Y. Pan, Q. Chen, N. Zhang, Z. Li, T. Zhu, and Q. Han, "Extending delivery range and decelerating battery aging of logistics UAVs using public buses," *IEEE Transactions on Mobile Computing,* vol. 22, no. 9, pp. 5280-5295, 2022.

[64]A. Albatayneh, A. Juaidi, M. Jaradat, and F. Manzano-Agugliaro, "Future of electric and hydrogen cars and trucks: an overview," *Energies,* vol. 16, no. 7, p. 3230, 2023.

[65]R. Shinnar, "The hydrogen economy, fuel cells, and electric cars," *Technology in society,* vol. 25, no. 4, pp. 455-476, 2003.

[66]D. W. Keith and A. E. Farrell, "Rethinking hydrogen cars," vol. 301, ed: American Association for the Advancement of Science, 2003, pp. 315-316.

[67]D. Ross, "Hydrogen storage: the major technological barrier to the development of hydrogen fuel cell cars," *Vacuum,* vol. 80, no. 10, pp. 1084-1089, 2006, doi: https://doi.org/10.1016/j.vacuum.2006.03.030.

[68]S. M. Katalenich and M. Z. Jacobson, "Toward battery electric and hydrogen fuel cell military vehicles for land, air, and sea," *Energy,* vol. 254, p. 124355, 2022, doi: https://doi.org/10.1016/j.energy.2022.124355.

[69]W. T. Mikolowsky and L. W. Noggle, "The potential of liquid hydrogen as a military aircraft fuel," *International Journal of Hydrogen Energy,* vol. 3, no. 4, pp. 449-460, 1978, doi: https://doi.org/10.1016/0360-3199(78)90005-8.

[70]K. D. Pointon and B. Lakeman, "Prospects for hydrogen as a military fuel," in *Assessment of Hydrogen Energy for Sustainable Development*: Springer, 2007, pp. 97-106.

[71]N. Sifer and K. Gardner, "An analysis of hydrogen production from ammonia hydride hydrogen generators for use in military fuel cell environments," *Journal of power sources,* vol. 132, no. 1-2, pp. 135-138, 2004, doi: https://doi.org/10.1016/j.jpowsour.2003.09.076.

[72]A. Soboń, D. Słyś, M. Ruszel, and A. Wiącek, "Prospects for the use of hydrogen in the armed forces," *Energies,* vol. 14, no. 21, p. 7089, 2021, doi: https://doi.org/10.3390/en14217089.

[73]M. T. Ahad, M. M. H. Bhuiyan, A. N. Sakib, A. Becerril Corral, and Z. Siddique, "An overview of challenges for the future of hydrogen," *Materials,* vol. 16, no. 20, p. 6680, 2023, doi: https://doi.org/10.3390/ma16206680.

[74]S. E. Hosseini and B. Butler, "An overview of development and challenges in hydrogen powered vehicles," *International Journal of Green Energy,* vol. 17, no. 1, pp. 13-37, 2020, doi: https://doi.org/10.1080/15435075.2019.1685999.

[75]M. Prewitz, A. Bardenhagen, and R. Beck, "Hydrogen as the fuel of the future in aircrafts–Challenges and opportunities," *International Journal of Hydrogen Energy,* vol. 45, no. 46, pp. 25378-25385, 2020, doi: https://doi.org/10.1016/j.ijhydene.2020.06.238.

[76]B. Sarlioglu and C. T. Morris, "More electric aircraft: Review, challenges, and opportunities for commercial transport aircraft," *IEEE transactions on Transportation Electrification,* vol. 1, no. 1, pp. 54-64, 2015, doi: https://doi.org/10.1109/TTE.2015.2426499.

[77]Y. Gu, M. Wiedemann, T. Ryley, M. E. Johnson, and M. J. Evans, "Hydrogen-powered aircraft at airports: a review of the infrastructure requirements and planning challenges," *Sustainability,* vol. 15, no. 21, p. 15539, 2023, doi: https://doi.org/10.3390/su152115539.