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BEYOND ROTORS: SOLID-STATE DRONE TECHNOLOGIES AS THE NEXT GENERATION OF UNMANNED AERIAL SYSTEMS

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Abstract. This study examines the solid-state approach, which is gaining increasing importance in aviation technologies, within the framework of a new system design paradigm. The solid-state concept is based on the realization of fundamental functions such as propulsion, sensing, steering, and communication using electronic, electromagnetic, and semiconductor-based structures without relying on moving and mechanical components. This approach offers significant advantages, particularly in eliminating mechanical wear, reducing maintenance requirements, extending system lifespan, and minimizing acoustic and electromagnetic signatures. In this study, the architectures of traditional unmanned aerial vehicles (UAVs) are first examined, and the vibration, noise, energy loss, and failure risks caused by their reliance on rotating propellers, brushless DC motors, servo-controlled aerodynamic surfaces, and mechanically scanned LiDAR or radar systems are evaluated. Considering these issues, alternative solutions offered by solid-state based drone systems are assessed. In this context, electroaerodynamic (EAD) propulsion systems are considered as an innovative approach that provides thrust generation without rotating parts, based on the principle of accelerating ionized airflows through electric fields. Similarly, solid-state LiDAR technologies, which do not require mechanical scanning, offer high-precision three-dimensional sensing capabilities using semiconductor-based light steering methods. In the field of communication and sensing, phased array antennas provide directional and adaptive communication without the need for moving parts, thanks to their electronic beam steering capabilities. In conclusion, it has been shown that the holistic solid-state approach enables the development of quiet, reliable, and low-maintenance aerial platforms, as well as paving the way for next-generation applications such as micro and nano-scale aerial vehicles, indoor operations, and swarm-based autonomous systems.

Key words: solid-state drones, electroaerodynamic propulsion (EAD), low-observable UAV systems, silent noise UAVs, low-noise UAVs.

Introduction

The history of unmanned aerial vehicles (UAVs) dates back to the fire balloons of the mid-19th century and Tesla's remote-controlled boat experiments in 1898 [1]. However, the concept of solid-state propulsion entered scientific literature shortly after the discovery of electricity, with Francis Hauksbee's observation of the ionic wind phenomenon in 1709 [2]. In the 1920s, Thomas Townsend Brown's work, which he called the «Biefeld-Brown effect» but was later understood to be electrohydrodynamics (EHD), paved the way for devices that did not operate in a vacuum and only produced thrust in atmospheric air [3].

In the 1960s, Major Alexander Prokofieff de Seversky obtained patents for ionic vehicles, which he called «ionocraft», powered by an external power source and capable of vertical takeoff. However, these early studies could not be developed into self-powered (onboard power) vehicles due to the weight and low thrust density of high-voltage power sources [4]. The turning point came in 2018 when the MIT team led by Steven Barrett flew the «EAD Airframe Version 2» aircraft, which has no moving parts and carries its own battery system [5].

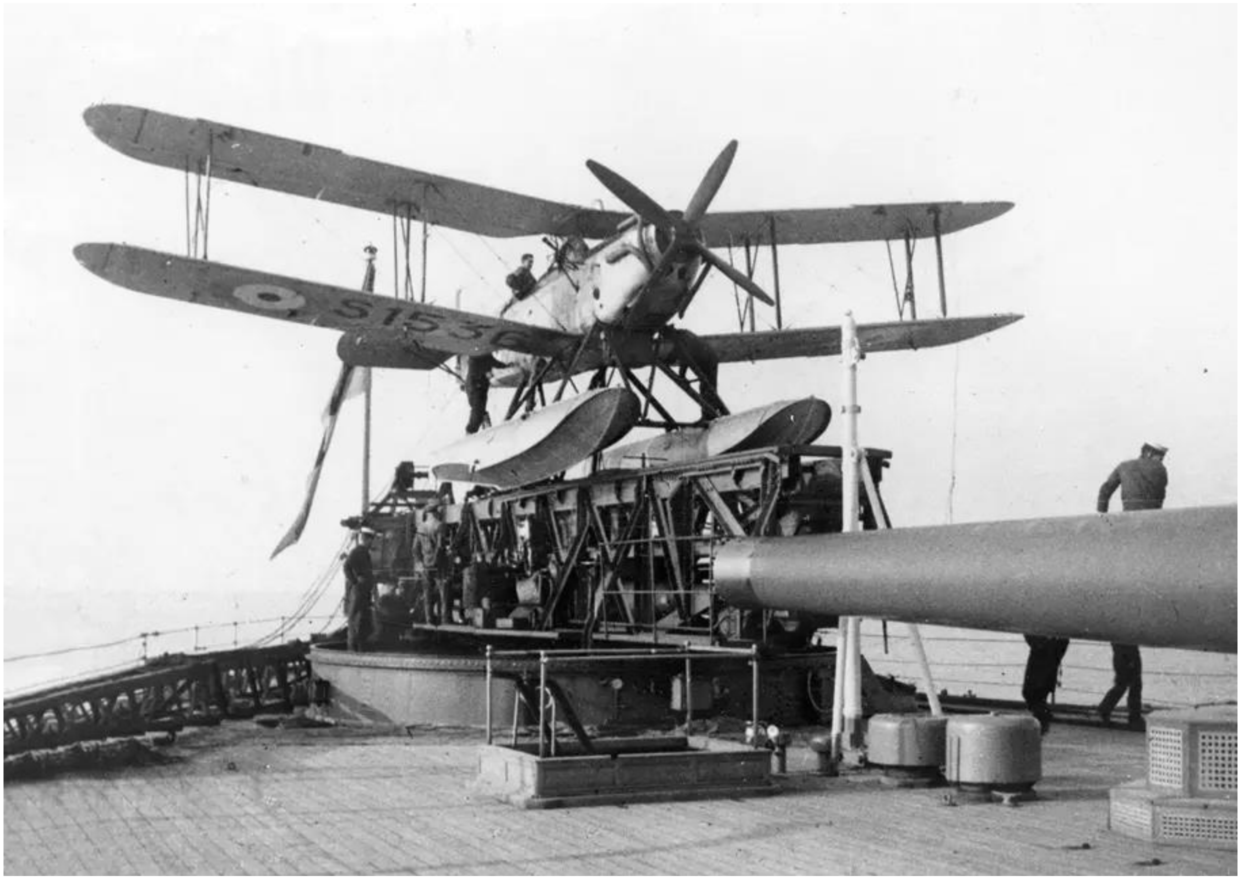

Figure 1. In the 1930s, the British converted biplanes into radio-controlled target drones, beginning with the Fairey Queen IIIF Mk.IIIB (on the aft deck of a Royal Navy vessel) [1].

Table 1.The historical developments in solid-state components

Period	Significant Development	Solid-State Component	Reference
1709	Discovery of Ionic Wind (F. Hauksbee)	Physical Principle	[2]
1920-50	Biefeld-Brown Effect and EHD Experiments	Early Prototype Concepts	[3]
1960	Ionocraft Patents (A. de Seversky)	VTOL Designs	[8]
2006	First Onboard Powerful Ionic Takeoff (E. Krauss)	Power Electronics Integration	[9]
2018	First Solid State Fixed-Wing Flight (MIT)	Completed EAD System	[6]

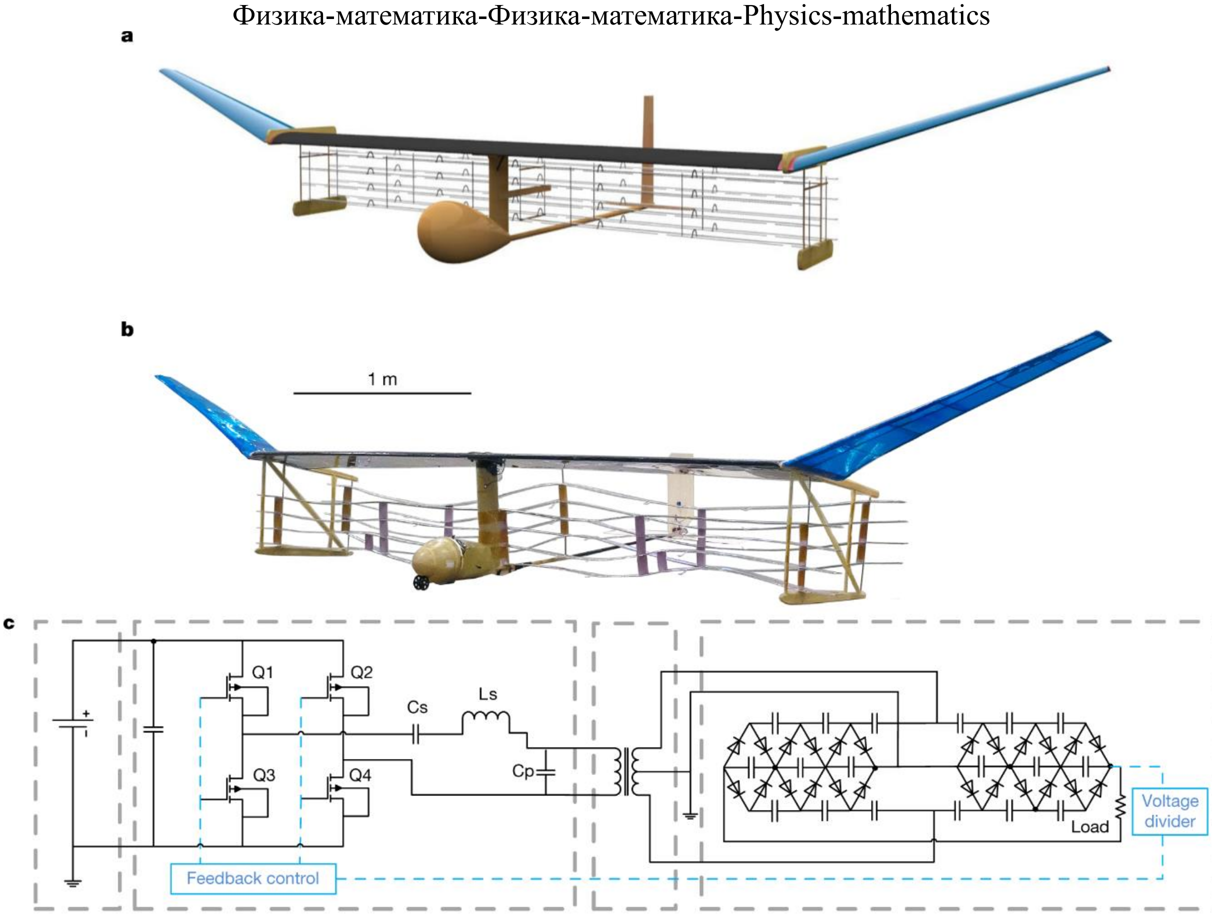

Figure 2. a. Computer-generated rendering of the EAD aeroplane. b. Photograph of actual EAD aeroplane (after multiple flight trials). c. Architecture of the high-voltage power converter (HVPC)

In multirotor UAV architectures, the dominant component of noise is aeroacoustic sources arising from propeller-flow interaction, with motor-related components contributing additionally, especially at high frequencies [8]. In parallel, in cases of imbalance between rotating propellers and the motor/shaft group, wing damage, or bearing problems, the vibration spectrum is significantly increased. These vibrations both impair flight stability and lead to motor-propeller failures being considered a critical risk class in fault diagnosis literature [9]. From an energy efficiency perspective, in small multirotor platforms, range and flight duration are mostly limited by battery capacity and power to the rotors, and therefore rotor-related energy consumption is reported as a decisive constraint on mission duration [10]. For servo actuators used on the steering side, it has been shown that failure types such as «stuck/loose» directly affect flight, and reliability analyses have been conducted at the architectural level [11]. Finally, mechanical scanning LiDAR/radar solutions are considered in opto-mechanical/electromechanical subcategories due to their «scanning mechanism», while solid-state approaches are systematically classified in the literature as alternatives aimed at reducing moving mass [12].

Traditional UAVs, and especially multi-rotor drone systems, despite their widespread use in many civilian and military fields in recent years, have significant disadvantages due to their structural and physical limitations. The basic architecture of these systems is based on brushless direct current (BLDC) motors and rotating propellers for thrust generation. Although this structure offers a simple, low-cost, and relatively easy-to-control solution, it brings with it critical problems such as heat generation, noise, atmospheric signature, and detectability. Although brushless motors are considered efficient in terms of mechanical friction, they generate a significant amount of thermal energy due to high-speed operation.

This heat generated in motor windings, power electronics units (ESCs), and battery packs reduces system efficiency, especially during long flights, and increases the need for thermal management. The resulting temperature increase not only shortens the lifespan of the components but also makes the drone's thermal signature more prominent, making it easily detectable by infrared (IR) and thermal cameras. This poses a serious vulnerability in military, security, or covert operations. Furthermore, rotating propellers are in constant, high-energy interaction with the atmosphere. This interaction creates turbulence in air currents, leading to the creation of an atmospheric signature. Especially in humid or high-particle density environments, propeller-driven air movements can be tracked by laser-based detection systems or sensitive optical sensors. Additionally, the high speeds at the propeller tips create micro-scale pressure fluctuations, resulting in a characteristic flow signature within the air.

One of the most significant disadvantages of traditional drone systems is acoustic noise. Aerodynamic noise and motor vibrations generated by the rotation of the propellers make the drone easily detectable audibly, especially at low altitudes. This noise can be detected not only by the human ear but also from miles away using advanced acoustic detection and navigation systems. The noise level reduces mission stealth and becomes a significant factor limiting their use in urban areas. Furthermore, the presence of mechanical components brings with it long-term reliability issues such as vibration, balance problems, and mechanical wear. Rotating parts experience performance loss over time, increasing maintenance requirements and raising the probability of failure. This poses a serious disadvantage, especially for swarm drone systems or autonomous long-duration missions. In conclusion, traditional drones, due to their brushless motor-based structure, have fundamental disadvantages such as high heat generation, significant thermal and acoustic signatures, detectability due to atmospheric interference, and mechanical wear. These limitations mean that current drone technologies are insufficient, especially in applications requiring stealth, robustness, and a low footprint, clearly highlighting the need for next-generation, moving-part-free, and low-footprint aerial vehicle approaches.

Materials and methods of research

2. Solid-State Drone Systems

2.1. ElectroAerodynamic (EAD) Propulsion Systems and Ionic Wind

EAD thrust is based on the principle of ionizing atmospheric air and accelerating these ions in an electric field, resulting in momentum transfer through collisions with neutral air molecules [7]. Unlike conventional propellers, the thrust produced in this process is completely silent and does not produce any combustion emissions [6]. For the system to work, a high voltage (usually 20-50 kV) is first applied between two asymmetric electrodes. A very thin wire (usually less than 200 μm in diameter) called the emitter (anode) and a thicker structure called the collector (cathode) are used [13]. The very strong electric field near the emitter creates a plasma by stripping electrons from air molecules. In the positive corona regime, the resulting positive ions are pushed towards the collector, colliding with neutral molecules and creating an ionic wind [7]. Here, nitrogen ions (positive polarity) and oxygen ions (negative polarity) act as the primary charge carriers.

2.2. Mathematical Modeling of EAD Thrust Systems

Modeling the EHD thrust requires an approach that combines the behavior of ion movement in an electric field and the effect of this movement on the neutral gas [14]. The current density (j) in the ion drift region is expressed by equation (1) when charge diffusion and convective effects are neglected.

$$j = \rho_q \left(\mu_q E + v_b \right) \tag{1}$$

Here, ρ_q represents the charge density (C/m^3), μ_q represents the ion mobility ($m^2/V.s$), E represents the electric field strength (V/m), and v_b represents the velocity of the fluid (air) (m/s). Ion mobility indicates the resistance of ion movement in the medium and is accepted as approximately $2.0 * 10^{-4} m^2/V.s$ for air at room temperature [14]. In a static medium ($v_b = 0$) and under the space charge limited current regime, the current density obeys the Mott-Gurney law and is calculated by equation (2) [14].

$$J = \frac{9}{8}\epsilon\mu\frac{V^2}{d^3} \tag{2}$$

Here, ϵ represents the dielectric permittivity of air, V the applied potential difference, and d the distance between the electrodes. This relationship determines the critical limits of the design parameters by showing that the current density is directly proportional to the square of the voltage and inversely proportional to the cube of the distance [15]. When performing thrust force and efficiency calculations, the total EHD force produced in the system (F_{EHD}) is calculated as the integral of the volumetric Coulomb force and included in the calculation. This calculation is done as shown in equation (3) [16].

$$F_{EHD} = \iiint_v \rho_q E dV \tag{3}$$

However, in a one-dimensional (*1D*) simplified model, the total thrust (*T*) corona flow (*I*) and thrust-power ratio *(θ)* are calculated by equations (4) and (5) respectively, and these are the only criteria considered in the energy efficiency of the system [17].

$$T = \frac{I.d_{drift}}{\mu} \tag{4}$$

$$\theta = \frac{T}{P} = \frac{d_{drift}}{\mu V} \tag{5}$$

2.3. Aerodynamic Drag and Thrust

In a real flight scenario, the aerodynamic drag of the thruster assembly itself dampens some of the generated ionic wind. In this case, the effective thrust *(T_{eff})* is equal to the difference between the total ionic force and the structural drag [18].

$$T_{eff} = T_{EHD} - \frac{1}{2}\rho v^2 A C_d \tag{6}$$

2.4. LiDAR and Localization

The environmental awareness and positioning of solid-state drones rely on sensor technologies that do not involve mechanical scanning. These systems form the basis of autonomous flight with their high-frequency data acquisition capabilities and low error margins. Solid-state LiDARs use MEMS mirrors or optical phase arrays (OPA) to direct the light beam [19]. The coordinates of a point *(P_n)* detected by the sensor in the LiDAR reference system are calculated using the Time-of-Flight *(ToF)* measurement and the scan vector *($\hat{s}_n$)*. These operations are performed using equation (7), where C is the speed of light. The dynamics of the MEMS mirrors used for beam direction are modeled by Vector Snell's Law, and equation (8) is used for this operation [20].

$$P_n = \frac{C}{2} t_{ToF,n}.\hat{s}_n \tag{7}$$

$$\hat{r} = \mu\hat{\imath} - \left[\mu(\hat{n}.\hat{\imath}) + \sqrt{1-\mu^2(1-(\hat{n}.\hat{\imath})^2)}\right]\hat{n} \tag{8}$$

Since air is generally used in LiDAR systems, $\mu = 1$ is taken. However, the inner product *($\hat{n}.\hat{\imath}$)* between the normal vector of the mirror *($\hat{n}$)* and the incident ray *($\hat{\imath}$)* produces a nonlinear term that causes optical distortion in the scanning area. To eliminate these distortions, camera-like calibration methods are applied, and each pixel is associated with the scanning direction [20].

The MEMS-based Inertial Measurement Unit (IMU), used for drone positioning and attitude estimation, combines accelerometer and gyroscope data [24]. Although these sensors are resistant to shock and vibration thanks to their solid-state structures, they also have stochastic errors that accumulate over time. The Allan Variance (AV) method is used for IMU noise characterization. This method represents the root mean square (RMS) random deviation error as a function of the mean time, and the total noise spectral density *(S_n)* consists of random walk *(N)*, bias instability *(B)*, and ratio random walk *(K)*.

$$S_n(f) = N^2 + \frac{B^2}{2\pi f} + \frac{K^2}{(2\pi f)^2} \tag{9}$$

where, *N (Random Walk):* This is the term for white noise. It is called angular random walk (ARW) for gyroscopes and velocity random walk (VRW) for accelerometers.

B (Bias Instability): This is the term for pink noise (flicker noise) and determines the lowest noise floor that the sensor can reach.

K (Ratio Random Walk): This is the term for brown noise and represents long-term deviations in the bias value [27].

2.5. Sensor Fusion and Calibration

To eliminate deviations in IMU data, Kalman Filter (KF) or Extended Kalman Filter (EKF) is used. KF structures combined with «No Motion No Integration» (NMNI) algorithms are preferred, especially to suppress high-frequency noise caused by engine vibrations. This fusion can reduce the error margin in roll and pitch angles to levels of 0.02° - 0.03°.

In IMU-based attitude estimation, data obtained from accelerometer and gyroscope sensors can show significant deviations over time due to bias drift, scale errors, and especially engine-induced vibrations. Therefore, direct integration of raw IMU data does not offer an acceptable solution in aircraft applications requiring long-term and accurate attitude estimation. To overcome these problems, one of the most commonly used methods in literature is the Kalman Filter (KF) and its generalized form for nonlinear systems, the Extended Kalman Filter (EKF). KF/EKF-based approaches suppress noise and provide more stable state estimation by statistically combining the system's dynamic model and sensor measurement uncertainties.

Especially in multi-rotor drone systems, high-frequency mechanical vibrations caused by brushless motors and propellers lead to sudden and irregular fluctuations in accelerometer data. When such vibrations cannot be fully eliminated by classical filtering methods, serious errors can occur in attitude estimation, particularly in roll and pitch angles. At this point, the use of KF or EKF structures together with «No Motion No Integration» (NMNI) algorithms provides a significant improvement. The NMNI approach detects the time intervals when the system is stationary or semi-stationary, limiting unnecessary integration operations in these situations and effectively reducing gyroscope-induced drift accumulation.

The KF/EKF–NMNI fusion makes attitude estimation more reliable, especially in low-acceleration or hover mode flight conditions, while maintaining the physical consistency of sensor data. Consequently, supporting KF/EKF-based sensor fusion with situational awareness algorithms such as NMNI forms the basis of high-accuracy and vibration-resistant attitude estimation in modern drone systems.

2.6. Communication

Solid-state drone communication uses phased array antenna systems to provide directional transmission and high data rates. These systems electronically focus the signal beam on the desired direction without the need for a mechanical antenna tower. In phased array antennas, the phase difference (Δ_{φ}) between N number of antenna elements ensures that the beam is directed to the desired angle θ_S. The required phase shift between two consecutive elements is calculated as shown in equation (10).

$$\Delta_{\varphi}=\frac{2\pi d}{\lambda}sin(\theta_S) \tag{10}$$

Here, d represents the distance between elements, and λ represents the wavelength. Increasing the number of antenna elements *(N)* increases directivity while decreasing the beamwidth, and the increase in directivity is calculated as approximately $10\,log_{10}(N)$ dB. The performance of the communication link is limited by the theoretical upper limit determined by the Shannon-Hartley theorem.

$$C = B\log_2\left(1+\frac{S}{N}\right) \tag{11}$$

Here *C* is channel capacity (bps), *B* is bandwidth (Hz) and *S/N* is signal-to-noise ratio (SNR). The relationship between received signal power (*S*), transmitted power *(P_t)*, antenna gains *(G)* and path loss *(L)* is calculated as shown in equation (12).

$$P_r(dBm) = P_t + G_t + G_r - L_p \tag{12}$$

The Doppler shift *(Δf)* caused by the moving nature of the drone affects the communication frequency. The communication frequency is calculated as shown in equation (13).

$$\Delta f = f_c\frac{v}{c}cos(\theta) \tag{13}$$

Here, *v* represents the drone's speed, f_c the carrier frequency, and θ the angle of approach. At speeds below 10 m/s, this effect is negligible, but it is critical for synchronization in high-speed solid-state drone operations. The path loss (PL) model used for drone communication in urban areas combines the effect of free space loss with environmental obstacles (buildings, trees). In a simplified air-to-ground (A2G) model, the path loss coefficient (*n*) varies depending on altitude.

$$PL(d) = PL_0 + 10n\log_{10}\frac{d}{d_0} + S \tag{14}$$

In millimeter wave (mmWave) transmissions, additional terms such as rain damping (L_R) and leaf loss (L_0) should also be added to the model. The Weissberger model is generally used for leaf loss. For urban building distributions, probabilistic line of sight *(PLoS)* calculations are performed using the Rayleigh building height distribution ($f(h)$).

2.7. Energy Storage and Power Management

The operational success of solid-state drones depends directly on the reliability and efficiency of the energy storage and power management infrastructure, as well as on the propulsion and control architectures. Lithium-ion (Li-ion) batteries, commonly used in current drone platforms, offer high specific energy but carry a risk of flammability due to their liquid electrolyte structure and are limited to a narrow thermal operating range. Especially in scenarios with high power draw, fast charge/discharge cycles, and increasing ambient temperatures, these batteries reduce operational safety due to the risk of thermal runaway. This constitutes a significant constraint for solid-state propulsion systems requiring high voltage and continuous power demand. In this context, solid-state batteries (SSBs) offer a significant technological alternative thanks to the use of solid ceramic or polymer electrolytes instead of liquid electrolytes. The solid electrolyte structure provides a more mechanically and chemically stable environment between the electrodes, suppressing dendrite formation and significantly reducing the risk of short circuits. This feature is critical for applications exposed to high electric fields, especially electroaerodynamic (EAD) propulsion systems.

In EAD-based propulsion architectures, stable and low-ripple DC voltages in the order of 20–40 kV are required for ionization and acceleration processes. These voltage levels are generated through ultra-light power converters (high-voltage DC-DC power converters) that operate under the constraints of lightness and efficiency. The high-efficiency operation of these converters depends on a stable, low-internal-resistance power source on the input side that can quickly respond to sudden load changes. Solid-state batteries offer a suitable DC supply infrastructure for such high-voltage converters due to their low internal impedance and more stable voltage characteristics. In addition, the high energy density offered by SSBs partially compensates for the relatively low thrust density disadvantage of ionic propulsion systems by increasing the payload capacity and flight time of the drone platform. Lighter and safer energy storage solutions increase the effectiveness of solid-state drones in scenarios such as long-duration missions, indoor operations, and autonomous swarm applications. In conclusion, the integrated use of solid-state batteries and high-efficiency power converters stands out as a key research and development area for the scalability and operational sustainability of solid-state drone technologies.

Results and its discussion

One of the most important points to note here is that efficiency is inversely proportional to the applied voltage [19]. That is, increasing the voltage to produce higher thrust also increases the power dissipated per unit Newton. In MIT experiments, it was determined that thyyanite can produce 110 Newtons per kilowatt, which is well above that of conventional jet engines (2 N/kW) [20]. However, the thrust density of EHD systems (3.3 N/m^2) is quite low compared to jet engines.

Wind tunnel tests conducted by Trovato and his team showed that the ionic thrust exhibited a parabolic trend, increasing slightly with flow velocity, but the effective thrust decreased quadratically due to the aerodynamic drag of the collectors [17].

Experimental results show that such hybrid filtering structures can reduce the error margin in roll and pitch angles to levels of 0.02°–0.03°. This level of accuracy is critical for both autonomous flight control algorithms and precision tasks (closed-space flight, stable imaging, swarm coordination).

Experimental studies reported in the literature show that SSBs can maintain their structural integrity and operate without thermal runaway even at temperatures of 100 °C and above.

Solid-state drone technologies represent one of the most radical technological breakthroughs in aviation history, challenging the dominance of propellers and jet engines. These systems, free from mechanical wear, offer a unique advantage, particularly in urban logistics and silent surveillance operations. Recent wind tunnel tests and theoretical modeling of electroaerodynamic propulsion systems have proven that ionic wind achieves sufficient thrust coefficients for sustainable flight even at low speeds. However, critical engineering barriers remain to overcome before the technology can be widely adopted on a commercial and industrial scale. In this interdisciplinary field, the research focus for the next decade is expected to evolve towards integrated solid-state platforms where propulsion, control, and communication architectures are completely free of moving parts. In this context, the concept of integrated propulsive skins, which transform the entire surface of the aircraft into an active thrust generator by integrating electrodes into the structural outer casing, is a critical research area for reducing drag and increasing system efficiency. Multi-stage channel (MSD) thrusters, developed to overcome the low thrust density of ionic propulsion, offer architectures that can provide solid-state drones with vertical take-off and landing (VTOL) and hovering capabilities. In flight control, the goal is to replace mechanical rudder systems with electrode-based torque management approaches based on the dynamic shaping of electric fields. In addition, AI-powered autonomy for the efficient management of solid-state LiDAR and phased array antennas is gaining importance, especially in the context of real-time beamforming optimization through neural networks fed with IMU data. Finally, the integration of hybrid ionic-conventional propulsion systems for large-scale platforms and micro-scale biomimetic designs with solid-state propulsion are among the key research directions that will expand the scalability and application spectrum of the technology.

As a result, solid-state drones are not only a quiet and clean means of transportation, but also a massive technological laboratory where materials science, high-voltage electronics, and artificial intelligence converge. Targets to increase ionic mobility and high-voltage efficiency to 15% will ensure these vehicles become a standard feature in urban skies in the near future.

Conclusion

Solid-state drone technologies offer a future of aviation that is free from mechanical complexity, quiet, and highly reliable. Mathematical models of electroaerodynamic propulsion show that the system's efficiency is maximized at low speeds and that thrust density can be optimized with electrode geometry (within Mott-Gurney constraints) [20]. The use of MEMS and phased array technologies in sensing and communication systems frees the drone's environmental awareness and data transmission capacity from mechanical limitations. With the commercial maturity of solid-state batteries, it is considered an inevitable technological evolution that these quiet and environmentally friendly vehicles will become the standard in logistics and strategic surveillance missions.

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РОТОРСЫЗ: ҚАТТЫҚҮЙЛІ ДРОН ТЕХНОЛОГИЯЛАРЫ ҰШҚЫШСЫЗ ӘУЕ ЖҮЙЕЛЕРІНІҢ КЕЛЕСІ БУЫНЫ РЕТІНДЕ

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Аңдатпа. Бұл зерттеу авиациялық технологияларда маңызы артып келе жатқан қаттықүйлі тәсілді жаңа жүйелік жобалау парадигмасы аясында қарастырады. Қаттықүйлі тұжырымдама қозғалтқыш, сезу, басқару және байланыс сияқты негізгі функцияларды қозғалмалы және механикалық компоненттерді қолданбай, электрондық, электромагниттік және жартылай өткізгіштік құрылымдар арқылы жүзеге асыруға негізделген. Мұндай тәсіл механикалық тозуды жою, техникалық қызмет көрсету қажеттілігін азайту, жүйенің қызмет ету мерзімін ұлғайту, сондай-ақ акустикалық және электромагниттік белгілерді төмендету сияқты маңызды артықшылықтарға ие.

Зерттеу барысында алдымен дәстүрлі ұшқышсыз ұшу аппараттарының (ҰҰА) архитектуралары талданып, айналмалы пропеллерлерге, щеткасыз тұрақты ток қозғалтқыштарына, сервобасқарылатын аэродинамикалық беттерге және механикалық сканерленетін LiDAR немесе радиолокациялық жүйелерге тәуелділіктен туындайтын діріл, шу, энергия шығындары мен істен шығу тәуекелдері бағаланады. Осы мәселелерді ескере отырып, қаттықүйлі дрон жүйелері ұсынатын балама шешімдер қарастырылады.

Атап айтқанда, электроаэродинамикалық (EAD) қозғалыс жүйелері иондалған ауа ағындарын электр өрістері арқылы жеделдету принципіне негізделген, айналмалы бөлшектерсіз тарту күшін қамтамасыз ететін инновациялық тәсіл ретінде қарастырылады. Сол сияқты, механикалық сканерлеуді қажет етпейтін қаттықүйлі LiDAR технологиялары жартылай өткізгіштік сәуле басқару әдістері арқылы жоғары дәлдіктегі үшөлшемді сезу мүмкіндіктерін ұсынады. Байланыс және сезу саласында фазаланған антенналық торлар электрондық сәуле бағыттау арқылы қозғалмалы бөлшектерсіз бағытталған және бейімделгіш байланысты қамтамасыз етеді.

Қорытындылай келе, кешенді қаттықүйлі тәсіл тыныш, сенімді және техникалық қызмет көрсету шығыны төмен әуе платформаларын әзірлеуге мүмкіндік беретінін, сондай-ақ микро- және наноөлшемді ұшу аппараттары, жабық кеңістіктерде жұмыс істеу және ройлық автономды жүйелер сияқты келесі буын қолданбаларына жол ашатынын көрсетеді.

Түйін сөздер: қаттықүйлі дрондар, электроаэродинамикалық тарту (ЭАТ), аз байқалатын ҰҰА жүйелері, дыбыссыз ұшқышсыз аппараттар, төмен шулы ұшқышсыз аппараттар.

БЕЗ РОТОРОВ: ТВЕРДОТЕЛЬНЫЕ ТЕХНОЛОГИИ ДРОНОВ КАК СЛЕДУЮЩЕЕ ПОКОЛЕНИЕ БЕСПИЛОТНЫХ АЭРОСИСТЕМ

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Аннотация. В данной работе рассматривается твердотельный подход, который приобретает всё большую значимость в авиационных технологиях, в рамках новой парадигмы проектирования систем. Твердотельная концепция основана на реализации ключевых функций — таких как тяга, зондирование, управление и связь — с использованием электронных, электромагнитных и полупроводниковых структур без опоры на движущиеся и механические компоненты. Такой подход обладает рядом существенных преимуществ, включая устранение механического износа, снижение требований к техническому обслуживанию, увеличение срока службы системы, а также минимизацию акустических и электромагнитных сигнатур.

В работе сначала анализируются архитектуры традиционных беспилотных летательных аппаратов (БПЛА), а также оцениваются вибрации, шум, энергетические потери и риски отказов, обусловленные использованием вращающихся пропеллеров, бесщёточных двигателей постоянного тока, сервоприводов аэродинамических поверхностей и механически сканируемых систем LiDAR или радиолокации. С учётом выявленных ограничений анализируются альтернативные решения, предлагаемые твердотельными беспилотными системами.

В частности, электроаэродинамические (EAD) двигательные установки рассматриваются как инновационный подход, обеспечивающий создание тяги без вращающихся элементов за счёт ускорения ионизированных воздушных потоков в электрических полях. Аналогичным образом, твердотельные технологии LiDAR, не требующие механического сканирования, обеспечивают высокоточную трёхмерную визуализацию на основе полупроводниковых методов управления световым лучом. В области связи и зондирования фазированные антенные решётки позволяют реализовать направленную и адаптивную связь без движущихся частей благодаря электронному управлению диаграммой направленности.

В заключение показано, что комплексный твердотельный подход позволяет создавать малошумные, надёжные и малозатратные в обслуживании летательные платформы, а также открывает путь к разработке систем следующего поколения, включая микро- и нанобеспилотники, решения для полётов в закрытых пространствах и рой-ориентированные автономные системы.

Ключевые слова: твердотельные дроны, электроаэродинамическая тяга (EAD), малозаметные БПЛА, бесшумные беспилотные системы, низкошумные беспилотные системы.