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Research Progress on UAV Power Systems

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Abstract. In recent years, unmanned aerial vehicle (UAV) technology has been developing rapidly. As a new economic growth point, it is being deeply integrated into various sectors of the economy and society. Meanwhile, different power systems have been developed for UAVs, and they are applied in different scenarios according to their characteristics. This paper reviews the four existing UAV power systems, listing their features, advantages, and disadvantages, explaining their working principles, and presenting some application scenarios. Among them, fuel power systems have high power and long endurance, suitable for long-range missions; electric systems, in contrast, make UAVs more flexible, efficient, and low-emission, but are only suitable for small-scale operations. Hybrid systems and hydrogen energy systems are the two major future development trends, combining the advantages of the former two, but with the drawbacks of complex structure, immature technology, and requiring further development. This paper aims to popularize knowledge about UAV power systems and hopes to promote the advancement of this technology.

Keywords: UAV, power system, fuel power, electric drive, hybrid power

1. Introduction

In 2024, the Resolution of the Third Plenary Session of the 20th Central Committee of the Communist Party of China, titled **Resolution of the Central Committee of the Communist Party of China on Further Deepening Reform Comprehensively to Advance Chinese Modernization**, incorporated the development of general aviation and the low-altitude economy into the national development strategy system, charting the direction for the exploitation of low-altitude airspace and industrial innovation in China. Alongside the continued issuance of multiple supportive policies and the progressive improvement of the institutional environment, the demand for air transportation has gradually increased. Coupled with the rapid advancement of unmanned aerial vehicle (UAV) technology, the low-altitude economy is witnessing unprecedented opportunities for development. The low-altitude economy refers to a novel economic complex in which low-altitude aircraft engage in various public services, commercial activities, and other operational tasks within low-altitude airspace, covering multiple application areas such as education and healthcare [1]. At the same time, UAVs, with their notable advantages of manoeuvrability, real-time efficiency, and high spatial resolution, demonstrate broad application prospects in the agricultural sector. Strengthening the research and application of UAV technology and fully harnessing its effectiveness in precision irrigation, crop monitoring, plant protection operations, and other areas can effectively promote the

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green transformation of agriculture [2]. Nowadays, UAVs have also emerged in emergency rescue. High-rise building firefighting and rescue need to be innovated towards three-dimensional, automated, and even intelligent directions, while research and application of intelligent unmanned rescue systems are still in the developmental stage [3]. Driven by these fields, the requirements for UAV propulsion systems and energy sources are continuously rising, which directly affects capabilities such as flight endurance and payload efficiency. The fuel-powered propulsion system for UAVs is the longest-applied and most technologically mature propulsion system.

Relying on the high energy density of fuel and the maturity of engine technology, it meets the demands for payload, endurance, and high power. At the same time, electric propulsion systems are also developing continuously and have now been deployed on a large scale. With their low emissions, high manoeuvrability, and high efficiency, they have become the first choice for civil UAVs and are widely adopted by companies such as DJI and Zhongfei Technology. In order to align with current environmental concepts and new energy policies, integrating UAV propulsion systems with the frontier field of hydrogen energy can effectively address endurance issues and significantly improve overall efficiency. In the realm of hydrogen energy, the hydrogen-powered UAV project promoted by the Institute of Physics of the Chinese Academy of Sciences has achieved key breakthroughs, systematically resolving the contradiction between "water retention" and "oxygen mass transfer" in air-cooled fuel cells, and overcoming three key technologies: multi-scale regulation of catalyst layers, asymmetric water transport technology, and microchannel-enhanced heat transfer coupled with permanent heat management technology, thus laying a technical foundation for the future development of hydrogen-powered UAVs [4]. While being applied across multiple domains, UAV propulsion systems have also formed a development landscape with multiple technological routes coexisting, including fuel, electric, hybrid, and hydrogen energy.

The primary objective of this paper is to review the different propulsion systems, summarise their development status, and outline their development directions. First, it introduces the various propulsion systems, broadly categorised into hydrogen, fuel, electric, and hybrid power. Second, it analyses the characteristics of these four propulsion systems individually, pointing out their advantages and application scenarios. Finally, it summarises the development pattern in which multiple technological routes coexist, and provides an outlook on the application industry and future development of UAVs.The fuel power system was first used in automobiles and later widely applied to various aircraft. The fuels for UAV fuel propulsion systems include methanol, gasoline, or aviation kerosene. It is relatively rare in civil UAVs today and is mainly used as the power system for military UAVs. Piston engines and gas turbine engines cover most fuel power systems, and they have a mature industrial chain. This power system mainly converts the chemical energy of fuel into mechanical energy through an internal combustion engine, thereby driving the propeller to generate thrust. Its core process is "fuel storage → pressurized delivery → combustion work → mechanical transmission → thrust output". Because the energy density of fuel is high, almost 50 times that of lithium batteries, this power system performs excellently in endurance and payload, and also has relatively high power.

2. Fuel-powered propulsion system

Nowadays, environmental protection is a global priority, and urban low-altitude areas have increasingly strict requirements for noise and emissions. Some regulations reflect the shortcomings of fuel engines. Therefore, new processes and new technologies are very important for fuel engines, but due to their inherent limited potential, they are currently shifting toward hybrid development. On the other hand, alternative fuels such as green hydrogen are also being researched and developed,

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enabling UAVs to be clean and long-endurance while meeting environmental requirements. Although fuel power systems have disadvantages, they remain the mainstay for long-range and heavy-load operations, playing a significant role in the short and medium term, and are still irreplaceable by other systems.

Fuel power systems are mostly used in military applications, owing to the high energy density of the fuel, which enables UAVs to have high working power and long endurance. At the same time, benefiting from the technological development of aviation and piston engines and their early invention, this system has strong adaptability to missions and ample operational experience. The fuel power system is the ideal choice for UAVs that require long endurance and relatively large payloads. Piston engines and gas turbine engines also have their own characteristics. The former has low manufacturing cost and simple structure, but its drawbacks are low specific power and a service altitude of only 3,000 to 8,000 m; once at high altitude, performance degradation occurs, and high-altitude performance is severely limited. Based on these characteristics, piston engines are often used in some military reconnaissance UAVs or in short-duration missions. At the same time, the emergence of some compound piston engines has better compensated for some deficiencies, and they are commonly seen in small general aviation aircraft. According to statistics, by 2023, piston-powered aircraft accounted for 50% of China's general aviation fleet [5]. The latter, the gas turbine engine, has characteristics opposite to those of the piston type; it is suitable for missions at high altitude, high speed, and heavy load. This engine maintains a balance between power and efficiency, and also has a high power-to-weight ratio, giving UAVs excellent payload capacity and maneuverability, with endurance significantly longer than that of piston engines. However, its disadvantage is high manufacturing cost, which can be more than 10 times that of piston engines. In military use, this engine is typically used for reconnaissance-strike integrated UAVs, meeting the rigid requirements of weapon payload, high maneuverability, and long endurance [6]. In civil use, it is also the first choice for medium- and large-sized aircraft and long-range aircraft, accounting for 28%.

3. Electric power system

As eVTOL, electric general aviation aircraft, and various UAVs gradually become the core equipment of the low-altitude economy, the demand for high-performance power systems has become increasingly urgent. In UAM scenarios, with short ranges, low payloads, and stringent requirements for environmental noise, pure electric power technology, with its advantages of zero emissions, low noise, and low operating costs, is generally regarded as the mainstream route at the current stage [7]. The core component of the UAV electric power system is the electric motor, which drives the propeller to rotate and converts the electrical energy from the UAV battery into mechanical energy, providing lift for the UAV. The other parts of the system include the battery pack, which supplies power to the motor, typically lithium-ion batteries; the electronic speed controller, which intelligently adjusts the motor speed to regulate UAV power and ensure stability; the power distribution system, which allocates the power provided by the battery pack; and the flight control system, which serves as the UAV's control center and also has functions for real-time monitoring and data regulation. Overall, the pure electric system uses high-specific-energy batteries as an independent energy source, and through the energy conversion path of "energy storage – conversion – motor – thrust generator", it builds a highly integrated all-electric power architecture.

The electric power system has advantages in short-distance and small-scale delivery, etc., but due to its own structure and power limitations, it is still unable to undertake medium- and long-distance, heavy-load work. At the same time, electric UAVs also face problems such as short battery life, high

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cost of large aviation batteries, thermal runaway during charging, and significant performance degradation at low temperatures. Therefore, UAVs still cannot cover all aspects of the low-altitude economy, and combining with other power systems and technical routes to form a synergistic complementary hybrid technology is currently the optimal solution.

The main advantages of the electric power system are its simple structure, efficient operation, and compliance with environmental regulations with zero emissions. This system is the best choice for many civil UAVs or small- and medium-sized UAVs, and is adopted by leading UAV companies such as DJI and Zhongfei Technology. However, electric UAVs do not have the high-power characteristics of fuel power systems; therefore, electric UAVs generally adopt multi-rotor configurations and vertical take-off and landing (VTOL) fixed-wing configurations.

The DJI FlyCart 30, for example, adopts a multi-rotor configuration, with an excellent take-off mass of 95 kg and outstanding vertical take-off and landing capability and stable hover performance, making this structure dominant in cargo delivery, public services, and other fields. However, the drawback of this structure is that the energy density of its batteries is generally low; taking the commonly used lithium-polymer battery as an example, its energy density is only 180–240 W·h/kg [8], leading to low energy efficiency, weak endurance, and a range usually less than 50 km.

The vertical take-off and landing fixed-wing type, such as the Zhongfei Technology V50 UAV, not only has the excellent take-off and landing capability of the multi-rotor type but also the efficient cruise capability of the fixed-wing type. The power distribution system of this type optimizes the lift-to-drag ratio and also reasonably allocates electrical power, enabling the UAV to fly at high speed with long endurance. This model is a culmination of electric systems and has bright development prospects. However, this type still needs to solve the power allocation between level flight and take-off/landing, and has high requirements for battery power density and the electronic control system, requiring further technical breakthroughs in these areas.

4. Hybrid power system

The hybrid power system mainly refers to the combination of the traditional fuel power system and the electric power system, combining the advantages of both, with characteristics such as strong endurance, fast power response, and low emission pollution. It is the mainstream development direction for low-altitude aircraft at present, capable of handling both long-range, heavy-load missions and short-distance, short-duration operations. Its basic working principle is: a traditional engine drives a generator to provide power to the motors and propellers distributed on the UAV structure, while the motors provide the majority of the power to the propellers. The three main configurations of this system are series, parallel, and series-parallel.

The hybrid power system is a well-rounded system with excellent performance in endurance, power, and many other indicators. The core advantage of hybrid power lies in combining the high energy density of fuel with the flexibility and environmental friendliness of electric drive. Studies show that the fuel consumption rate of a hybrid system can be reduced by about 30% compared to a pure fuel system, and through intelligent energy management strategies such as fuzzy-logic-based dynamic power allocation [9]. As a future development trend for UAVs, the hybrid system is still under continuous development. It still faces some technical challenges, such as the conflict between complex systems and the trend toward lightweight UAVs, and the difficulty of energy management and distribution design. Currently, there are limited examples of hybrid UAVs, and further optimization and airworthiness certification are still needed.

In the series hybrid system, the engine is directly connected to the generator to produce electricity, which is then transmitted to the electric motor to generate power; at the same time, part

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of the electricity is also stored in the battery as an additional energy source. The advantage of this architecture is that it enables a more reasonable energy allocation strategy for the UAV. During low-power operation, the gas turbine engine keeps the UAV running in the high-efficiency operating zone; during high-power phases, such as take-off and landing, the battery's auxiliary power supply can meet the power demand at that time. For example, Honda's eVTOL uses this solution . The drawback of this structure is that it requires an independent generator, and to meet maximum power requirements, cost, volume, and weight all increase.

In the parallel hybrid system, the generator and the engine supply power separately. During startup, the starter-generator brings the engine to ignition speed; during steady flight, the generator switches to powering the UAV's equipment. The parallel type has two energy storage devices—fuel tank and battery pack—enabling reasonable allocation of fuel and electric power, so that the UAV can use energy efficiently during flight, achieving long range and reduced losses, and can be used for high-performance missions. This structure does not require an independent generator and is equipped with an integrated starter-generator, which reduces volume compared to the series type and also lowers fuel consumption. However, this structure has high demands on manufacturing technology and cost, and still requires continuous optimization.

The series-parallel type, also called the series-parallel hybrid, combines both configurations. On the basis of the parallel structure, it adds an additional generator, making the UAV more flexible. The additional motor can assist the main engine during high-power operations to meet power demands; during low-power operations, the main engine handles the driving work while the additional generator can charge the battery to store energy. In this mode, the UAV has ample power and greater flexibility to handle various emergencies. However, due to its complex structure and large volume, it is currently only used in small- and medium-sized UAVs.

5. Hydrogen power system

Hydrogen has been clearly identified as a key new economic growth point in China's "15th Five-Year Plan". With its advantages of zero pollution and high energy density, hydrogen has become the best candidate for new energy for UAVs and has extremely bright development prospects. However, hydrogen is also a flammable and explosive gas, and hydrogen storage remains a technical bottleneck. Currently, hydrogen power systems are mainly divided into two categories: hydrogen internal combustion systems and hydrogen fuel cell power systems.

At present, hydrogen power systems have been put into use in the UAV field, but only for experimental purposes. Hydrogen fuel cell systems remain the first choice for hydrogen-powered UAVs, and many technical difficulties are still being overcome, such as how to store hydrogen safely, how to reduce the manufacturing cost of hydrogen UAVs, how to avoid energy losses and excessive temperatures—these are all issues that urgently need consideration, and the safety of hydrogen UAVs must not be overlooked. Nevertheless, this system remains one of the development directions for achieving long-range, low-emission UAVs.

This system simply replaces the combustion of fuel with the combustion of hydrogen, while the rest is similar to the fuel power system. Because of its relatively mature technology, this hydrogen power system is the first choice for most UAVs. Compared with fuel power systems, hydrogen can provide more energy and output power, and is often used for long-endurance, long-distance work.

The hydrogen fuel cell power system is currently a major technical challenge, as it involves safe energy storage and other aspects. The core of this system is to directly convert hydrogen energy into electrical energy through electrochemical reactions, thereby driving the motor to turn the propeller. The advantages of this system are obvious: it achieves zero emissions, high power density, etc.

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Compared with hydrogen internal combustion systems, this system has higher energy conversion efficiency. With the same amount of hydrogen carried, the range of a fuel-cell-powered aircraft is about 150% that of an internal-combustion-powered model [10].

6. Conclusion

This paper mainly studies different UAV power systems, reviewing the existing fuel, electric, hydrogen, and hybrid power systems, and explaining the characteristics, working principles, and practical applications of each. The research purpose of this paper is to popularize knowledge about UAV power systems and to deepen scholars' understanding of UAV energy supply for reference. The analysis shows that different power systems, according to their respective characteristics, have been applied to different scenarios. The traditional fuel power system, with its advantages of high power and heavy payload, is still commonly used in military UAVs or long-range operations. In contrast, electric power has shown great application potential in urban life and civil UAVs; this system is low-noise, low-emission, and high-speed and efficient, thus favored by many, but due to shortcomings such as low battery energy density, it cannot yet perform long-distance missions. The hybrid power system is currently the mainstream development direction, combining the advantages of electric and fuel power systems, and balancing the needs of range, environmental protection, and power in the near term. The hydrogen power system is undoubtedly a key future development project; it not only has high power and high energy but also zero pollution; however, considering its safety and the immaturity of hydrogen storage technology, it cannot yet be applied on a large scale.

Nowadays, UAV power systems have formed a development pattern with multiple technical routes coexisting, and have become more intelligent. The significance of this paper is to analyze the current shortcomings of each power system and point out areas that need improvement, mainly in terms of power enhancement, structural optimization, more balanced energy management, and hydrogen energy application, so as to provide research directions for future scholars. It further promotes the vigorous development of the low-altitude economy and UAV technology, and facilitates UAVs becoming a major industry in the future, bringing efficiency improvements and convenience to people's lives and work.

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