A Design of Rapid Deployment Small Unmanned Aerial Vehicles

Yinjing Guo* , Lei Yang, Xianqi Song, and Xiaohan Guo

College of Electronic Communication and Physics, Shandong University of Science and Technology, Qingdao, 266590, China

*corresponding author e-mail: gyjlvh@126.com

Abstract. In view of the problems of slow deployment and high rescue costs when encountering sudden emergencies, a kind of rapid deployment small unmanned aerial vehicles was proposed. According to existing unmanned aerial vehicles technology, the principle of the unmanned aerial vehicles structure was analyzed and designed. Moreover, the launching device and the body protection cover were designed for the launching process. This unmanned aerial vehicle will play an important role in rapid disaster relief, exploration and large-scale data collection.

1. Introduction

Nowadays, the development and application of Unmanned aerial vehicles (UAVs) has been closely linked with our daily lives. It has played a major role in military training operations, civilian detection and disaster relief. Researchers has focus on the development technology of UAVs and has achieved great research results, such as the United States MQ-1 Predator, MQ-9 Reaper, RQ-4 Global Hawk, the Ravens and Hornets; Britain's the Mirage and the Spektre. "US Air Force Remotely Piloted Aircraft (RPA) Vector Report 2013-2038" was released in the United States on 2014. In the future, UAVs will support cross-domain collaborative development operations with high flexibility, mobility and seamless integration. It can undertake a wide range of tasks, such as intelligence, surveillance and reconnaissance (ISR), air interception, suppression or destruction of enemy air defense systems, electronic attacks, combat tasks, delivery of goods and other functions [1-3].

The need to complete the mission safely and steadily still is an important difficulty in the development of UAVs [4-5], such as the analysis of launch process factors, the design of launch segment control and simulation studies [6-8].

UAVs can only have the opportunity to complete the subsequent flight mission on the premise of a safe launch so that the launching process is a very important stage in the flight stage. UAVs take-off launches can use conventional launch methods such as boosting and rolling, vertical takeoff and landing, electromagnetic launches [9]. Based on those existing technology, this paper proposes a rapid deployment small UAV with electromagnetic ejection type and projectile type projection.

2. Design Concept

This kind of UAV is mainly based on the following three aspects to design, the first is the rapid deployment in the event of an accident. Emergency emergencies, especially when serious cause casualties, require rescue personnel to fully understand the spot situation and make countermeasures.
We need to find faster launching and cruising methods on existing UAVs technologies to achieve faster and more effective work methods than human work. The second is low-cost design. Utilizing UAVs instead of manpower for rescue work, especially in remote and complex environments, can greatly save manpower and reduce the casualties of rescue workers. Designing a one-time low cost UAVs will greatly reduce all aspects of resources consumption. The third is to achieve long working-time sustained. For distant forests and sites with large areas affected by disasters, the endurance capability will directly affect rescue. Starting from the structure to power consumption, so as to achieve the minimum energy consumption.

3. STRUCTURE DESIGN

Cannonball-type projection and electromagnetic catapult are used on this UAV. Before launched, it is placed in a metal enclosure. After the acceleration of the emission orbit, the UAV has a high exit speed which is much greater than take-off or ordinary fixed-wing UAV, so it can quickly reach a designated destination for missions. Inflatable wing adopt in order to reduce the volume, weight and cost. Before the metal enclosure falls off, the wing is in vacuum state and clings to both sides of the UAV. The propeller blade made of high-toughness, high-flexibility material so it can bent tightly against the inner wall. After the metal enclosure detached, the torsion spring pops the empennage and is secured with snaps to prevent the empennage from moving. The UAV mainly as gliding flight, supplemented by driving flight after the wing is inflated. After arriving at the destination, the scene data is collected and the result is fed back to the command center.

3.1. Transmission Scheme

Catapult take-off has liquid pressure catapult, elastic catapult, electromagnetic catapult and other methods. Electromagnetic ejection technology uses electromagnetic force as an acceleration method. It is a new type of launching method breakthroughs in traditional launch technologies that takes the UAV to takeoff speed within a short distance. Compared with the steam catapult, the electromagnetic catapult has the advantage of uniform acceleration, fast exit speed, good controllability, large energy output adjustment range, higher efficiency, low launch costs, short preparation period and emission concealment.

A rectangular guide vehicle is suspended inside the guide channel of the electromagnetic ejector, the left and right sides of the guide vehicle are inlaid with a superconductive magnet underneath, the bottom superconducting magnet interacts with the electromagnet of the launch guide groove to ensure that the guide vehicle can suspended, the superconducting magnets on both sides interact with the electromagnets on both sides of the launch slot to push the guide car forward at a high speed, thereby launching the UAV placed on the guide car at a high speed.

3.2. Metal Enclosure Design

During the launch, it is placed in the cannonball-type metal enclosure to avoid the fast speed caused damage. From a fluid mechanics point of view, the streamlined type design make the lower air resistance when flying in the air. As shown in Fig. 1, on the one hand, the shell protects the UAV’s body, and on the other hand, it uses cannonball-type projection to obtain the shortest launch time and the longest distance. A one-way inlet valve is installed on both sides of the shell to inflate the wing.
3.3. Inflatable Wing Design

Considering that the flexible inflatable structure is not easy to control deformation and the difficulty in processing, several simple symmetric airfoils were selected from the standard airfoil library. We selected NACA0010, NACA0012, NACA0016, NACA0018 and NACA0020, as shown in Fig. 2. The biggest difference in shape between them is that the maximum thickness of the airfoil is different. The maximum thickness of the NACA0020 airfoil is 20% of its chord length.

![Standard airfoil](image)

**Figure 2.** Standard airfoil.

Calculate the aerodynamic parameters of the five standard airfoils selected during the change in attack angle from -3° to 13°. In the calculation, the speed is set to Mach 0.3 and the Reynolds number is 50000. As shown in Fig. 3.

![Lift resistance ratio curve](image)

**Figure 3.** Lift resistance ratio curve.

The NACA 0016 airfoil has a relatively high maximum lift-to-drag ratio, and the higher lift-to-drag ratio range is still relatively large. The specific values of the lift and drag coefficients for the inflatable airfoil and the original airfoil are shown in Table 1. Compared with the original airfoil, the inflatable airfoil reduced the lift coefficient by 23.3%, the drag coefficient by 110%, and the lift-drag ratio decreased by 63.6%.
Among the numerous UAV design parameters, there are mainly three parameters that have a decisive influence on the overall, a) The maximum take-off weight of UAV \( W_u \); b) Sea level static force of power plant \( T_p \); c) Wing area \( S \).

The above three parameters are usually combined to give two relative parameters, a) The loading distribution on wings \( W_u / S \); b) Weight ratio \( T_p / W_u \).

The initial values of the take-off weight \( W_u / S \), and \( T_p / W_u \) are generally selected based on the flight performance indicators and typical missions that were developed in the design requirements. The cruising state is first used as a design point to estimate \( W_u / S \), which is by the gravity and lift forces balanced in the cruising-flat state,

\[
W_u / S = \frac{1}{2g} \rho v^2 C_l
\]  

In the formula, \( W_u \) is the take-off weight, \( g \) is the gravity acceleration, \( S \) is the wing area, \( \rho \) is the air density, \( v \) is the cruise speed. \( C_l \) is the lift coefficient of a three-dimensional wing. The airfoil has the most favorable pressure distribution near its designed lift coefficient. The airfoil has the smallest drag coefficient and a large lift-to-drag ratio. The preliminary estimate temporarily takes 0.9. This data can be corrected based on the aerodynamic calculation results of the final selected airfoil. \( W_u / S = 7.94 \text{kg} / \text{m}^2 \) can be calculation. The take-off weight expression is

\[
W_u = \frac{W_1 + W_2}{1 - f_s - f_t}
\]

\( W_1 \) is the effective mission payload weight is 0.80kg. \( W_2 \) is the weight of the power plant, referencing each of the existing motors parameters, comprehensive consideration can choose Scorpion HKIII-4035 motor, weight is about 455g, preliminary analysis taken \( W_2 \) as 0.56kg. \( f_s \) is the structural weight coefficient, and the weight coefficient of the small UAV structure within a few kilograms of the general take-off weight is in the range of 0.25–0.35. Take 0.35 as the preliminary design. \( f_t \) is the battery weight coefficient depends on the cruise speed, battery life, power plant efficiency, aerodynamic characteristics, and the actual specific energy of the battery. Its estimation formula is,

\[
f_t = \frac{g v t}{\eta_p K_{ld} \rho v^2}
\]

\( K_{ld} \) is the cruising lift-to-drag ratio, refer to the statistical value of 12, \( \eta_p \) is the efficiency of power plant, generally take 0.35, life time \( t \) is 1.5h, cruising speed \( v \) is 12m/s, substitute data can be obtained \( f_t \) is 0.408. \( S=0.71\text{m}^2 \) can be obtained according to (4).
The skin material of the inflatable wing needs to meet the requirements of light weight, good airtightness, strong tear resistance, soft and foldable. This design uses a composite material with nylon and double-sided TPU coating. The inflatable wing is a capsule structure and uses a multi-air-beam integral air-inflation wing. The inscribed circle was screened and the inscribed circle intersecting one another from the leading edge to the trailing edge was selected, as shown in Fig. 4(a). The final design of the inflatable airfoil is shown in Fig. 4(b).

![Figure 4](image_url)

**Figure 4.** The inflatable wing internal schematic diagram (a) Plane structure (b) Three-dimensional structure.

In order to improve the aerodynamic characteristics of the inflatable wing, the inflatable wing is covered with skin to reduce the resistance of the air and improve the wing lift coefficient. The inflation method is to install a one-way air intake hole controlled by a solenoid valve on the front side of the wing. When the UAV advances at a high speed, and the wing generates pressure between inside and outside, atmosphere can quickly fill the wing in a short time. When the internal and external pressure are consistent, the one-way inlet valve will automatically close and the inflation will be completed. The schematic diagram is shown in Fig. 5.

![Figure 5](image_url)

**Figure 5.** The inflatable wing schematic diagram: (a) One-way inflatable hole (b) Wing overall structure.

### 3.4. Tail Wing Design

The tail wing includes horizontal tail wing and vertical tail wing. The structure diagram is shown in Fig. 6. The main function of the tail wing is to manipulate the deflection to ensure the smooth flight.

In order to save the cost, the tail wing is designed to be embedded in the body. The wings are powered by the spring force of the torsion. Before and after state is shown in Fig. 7. It is characterized by its simple structure and no power unit.

![Figure 6](image_url)

**Figure 6.** Rear wing structure diagram.
3.5. Propeller Design

The propeller converts the engine's rotational power into propulsion by rotates in the air. Similar to the design concept of the rear wing, the soft material with strong toughness is selected, and the propeller blade can be arbitrarily bent. It is tightly against the inner wall of the metal enclosure. The blade expands under the effect of centrifugal force and blade restoring force. The schematic diagram of the bending and unfolding of the propeller is show in Fig. 8.

4. Rapid Deployment Small Unmanned Aerial Vehicles Workflow

The UAV's platform rapid emergency monitoring system monitors mission requirements based on actual conditions and emergency conditions, sets the flight path and cycle of UAV, and performs cruise missions. The UAV sends the captured video image to the ground station via the wireless transmission module. The ground station also receives heading, latitude, longitude, altitude, pitch angle, roll angle, camera angle. After detection of the incident module is processed, the location and scope of the accident site can be determined in real time, and highlighted in the monitoring interface to remind the ground personnel to confirm the situation on the spot and perform the rescue in time.

When the UAV performs a mission which is placed into electromagnetic catapult with metal enclosure. When the ground station shows that the UAV’s position is approaching the target location, the solenoid valve is opened and the air inlet is inflated with the internal and external pressures. When the pressure in the inflatable wing is equal to the outside pressure, the one-way inlet valve is closed. The aerated wing drove the UAV out of the metal enclosure, the tail was ejected and the propeller was rotated. The UAV continues to climb upwards due to inertia and buoyancy, reaching the incident scene. The metal enclosure falling-off with the act of airframe and gravity. For saving energy and extending the life, inflatable wings and propellers drove it forward.

The general operation flow for rapid deployment of emergency situations is shown in Fig. 9. The figure describes the framework of the UAV platform emergency monitoring system. The ground station performs image detection tasks in real time and feeds the results back to the command center, which sends the next motion instructions. In addition, satellite communication and mobile communication channels can be selected for image transmission and control channels.
The Simulation of UAV field work is shown in Fig. 10. The working states marked are as follows,

**State 1**, electromagnetic catapult ready to launch UAV; **State 2**, the UAV launched and it is wrapped in a shell;

**State 3**, inflatable wing solenoid valve opens and inflatable wing slowly inflates, its volume gradually becomes larger and the metal enclosure falls off. Tail wing and propeller unfold and continues to climb upwards using inertia;

**State 4**, the UAV to rise and climb over the obstacle by the propeller accelerates the speed;

**State 5**, the UAV enters the gliding state by the driving force decreases;

**State 6**, gliding halfway, intermittently tests distance from the destination and adjusts propeller rotation speed;

**State 7**, it arrives at the destination and begins to increase the speed of the propeller, lowering the speed of the fuselage, and preparing to enter the hovering state;

**State 8**, it hovered at the destination, measured and transmitted the data information back to the control center.

5. **Conclusion**
The use of electromagnetic catapults as a launching method for UAVs combined with cannonball-type projections can quickly respond to emergencies, not only responding quickly to accidents, providing a comprehensive observation and analysis of the accident scene, but also saving manpower and reduce the damage to personnel.

The main advantages of using inflatable wings are:
a) Collapsible, easy to carry and transport;
b) The structure is light in weight and small in size;
c) The principle is simpler and it is easy to design flexibly;
d) Low cost.

The electromagnetic catapult launching and missile projecting schemes we use have many advantages:

a) missile-type projection scheme. The shape of the UAV is streamlined. During the flight, the air resistance can be greatly reduced and the flight distance can be increased;
b) Accelerate evenly and power control stable;
c) It has a large energy output adjustment range;
d) The energy efficiency increased.

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