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# Design and Simulation of a Novel UAV Combined Fixed Wing and Quadrotor

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***Abstract:*** *Vertical takeoff and landing fixed-wing UAV is a special kind of UAV, that is, the fixed-wing UAV can take off and land vertically without using the runway. Compared with conventional UAVs, fixed-wing UAVs have the advantages of flexible takeoff and landing mode, convenient launch and recovery, good mobility and so on. Compared with multi-rotor UAVs, fixed-wing UAVs have the characteristics of longer endurance, faster speed and higher flight height. At present, the research and development of vertical takeoff and landing fixed-wing UAVs is still a hot research topic home and abroad. In this paper, a vertical take-off and landing fixed-wing UAV is designed according to the flight system of the quadrotor, including the overall design and structure design. The model of the vertical take-off and landing UAV based on aerodynamics, which is established in SolidWorks, is used for the simulation test carried out to simulate the vertical take-off and landing process of the UAV and the related functions of path tracking. Finally, the relevant parameters are obtained to verify the feasibility of the scheme.*

***Keywords:*** *quadrotor, structure design, vertical take-off and landing*

## 1. Introduction

There are a large number of scientific researches has been done on UAV (unmanned aerobic vehicles)[1-3]. Based on the past research, unmanned aerial vehicles (UAVs) has great prospects and is now widely used in agriculture, disaster relief, equipment management and other purposes[4-6]. The existing UAVs are divided into fixed wing UAVs, rotary wing UAVs and composite wing UAVs. Advantages of fixed wing UAV includes long endurance and high speed, so that they can be used for detection for large area which cannot be done manually, such as power line patrol and terrain measurement[7-9]. But they are limited by their lack of flexibility and complicated recovery[10-11]. For instance, the fixed wing UAVs cannot hover so it cannot make precise measurement and some of them need to rover by hitting the net and the Rotorcraft UAVs can make up for this defect[11]. There are more applications of the UAV due to the rotors, including accurate inspection of power lines through capturing the images of key apparatus, and helping crops to grow by pesticide spraying[12]. At the same time, the rotorcraft UAV has automatic obstacle avoidance function, so that it can work indoors with complex structure[13]. However, it suffers from a short cruise time.

Latitude Engineering LLC is the current world leader in vertical takeoff and landing fixed-wing UAV technology. Latitude Engineering has successfully developed the HQ family of products, and its quadrotor suite has been used to retrofit several unmanned aerial systems, including the Arcturus T-15 and Sensintel SilverFox B4. Latitude Engineering Vertical take-off and Landing fixed-wing UAV and modification kit uses the Piccolo autopilot specially developed by Cloud Cap Technology. Latitude Engineering currently develops UAV with three fixed-wing, the HQ-20, HQ-50 and HQ-60. Among them, in September 2016, the HQ-60 hybrid quadrotor UAV successfully set a new record of 22 hours, 29 minutes and 38 seconds for vertical takeoff and landing aircraft to stay in the air. The A160 had previously maintained a maximum flight time of 18 hours and 45 minutes.

There have also been some domestic advances in unmanned aerial vehicles. Sichuan AOSSCI Technology Co LTD (AOSSCI) unveiled to the public a new generation of self-developed intelligent aircraft, including the X-Hawk, a vertical take-off and landing fixed-wing drone, and X-Hound, a geeky member of the X family, in Beijing in September 2016. According to the introduction, the X-Hawk UAV can reach a top speed of 120 km/h, the maximum takeoff weight of 18 kg, the normal load of 3-5 kg, the ceiling of 5,000 meters, the maximum control range of 50 km. The propeller adopts a unique design of torque variable propeller, weighing the efficiency of the propeller in hovering and flying, which is the core technology of X-HAWK's long-endurance flight and the ability to switch between hovering and flat flight modes at any time. At the same time, the drone is capable of automatic reconfiguration after a powertrain failure. The development of the UAV has successfully filled the technical gap in China's UAV field of vertical takeoff, landing, and high-efficiency horizontal flight, and it will also be the world's first successful civilian tail-seat unmanned aerial vehicle.

In view of the above characteristics, this paper designs a composite wing UAV with both fixed wing and rotor wing. The modelling was done in SolidWorks. The simulation was done in Adams and SolidWorks. The research shows the mechanical design and verifies that the UAV is able to take off and cruise a rectangular trajectory.

In Section 2, a fixed-wing aircraft model for vertical takeoff and landing is presented, and the design scheme of specific related structures is described. The third part based on Adams and SolidWorks in the simulated gravity environment to establish the simulation. The simulation of vertical takeoff and landing and rectangular path tracking is also carried out. Finally, the fourth part summarizes the whole paper, and points out the defects and the future improvement work.

Based on the characteristics of UAV system, in this paper, we study the problems related to the fixed-wing aircraft which can take off and land vertically, and establishes the UAV model based on aerodynamics theory and UAV design theory.

## 2. The Structure design of Model

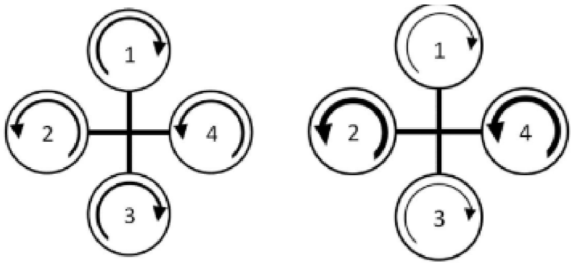
This chapter mainly carries on the photo overall structure design analysis to the vertical takeoff and landing fixed wing UAV. The design of the UAV has two kinds of power system, for rotor dynamic system of the main function of vertical take-off and landing of UAV in the work which will produce larger vibration and torque, and rotor part is mounted on the fixed above the wing, cause the aerodynamic force transmission to the wing, and the conduction to full unmanned aerial vehicles (UAV), Therefore, in the specific design of the wing and fuselage, the load distribution and related stress should be fully considered, and the appropriate stress mode and stress component layout should be selected.

### *2.1. The Theory of Quadrotor*

Quadrotor aircraft adopts four rotors as the direct power source of flight, and mostly adopts axisymmetric layout, as shown in the Fig.1. The four rotors are in the same height plane, two pairs of rotors rotating in the opposite direction, rotors I and 3 counterclockwise rotation, rotors 2 and 4 clockwise rotation, each rotor is directly connected to the brushless DC machine, the motor is symmetrically installed in the support end of the aircraft, the middle space of the support for flight control equipment and load.

(1) Vertical takeoff and landing and hover: Adding or subtracting all four rotors simultaneously increases or decreases the lift of the rotors. The thickness of the arrow represents the speed of rotation. When the total lift force produced by the four rotors is greater than or less than the gravity of the four rotors, the helicopter will rise or fall vertically. When lift equals gravity, it hovers in the air, as shown in Fig. 1(a).

(2) Horizontal rotation: The horizontal rotation of the quadrotor is achieved by reverse torque. The front and rear rotors are a group, and the left and right rotors are a group. When horizontal rotation of the quadrotor is expected, the output power of one group is increased while the output power of the other group is decreased by adjusting the rotational speed of the two groups, and the rotation direction is expected to be opposite to the rotation direction of the group with increased rotational speed. In this way, horizontal rotation of the quadrotor will be generated under the action of reverse torque, as shown in Fig. 1(b).




(a) (b)

*Figure 1: The concept of quatrodor*

### *2.2. The Overall Design*

The vertical takeoff and landing fixed-wing UAV adopt the conventional layout, and the wing adopts the single wing layout with medium aspect ratio. Due to the low speed of this UAV, it adopts the straight combined wing without sweep, and the airfoil thickness is moderate. To facilitate transportation and reduce occupancy, the wings are designed to be detachable and bolted to the fuselage. The quadrotor has a symmetrical layout, with the rotor shaft suspended equidistant from the wing and removable. Due to the existence of thrust screw, the tail beam design is simplified, extending from the bottom of the fuselage, and connected to the flat tail. The design of the UAV is shown in figure 2.

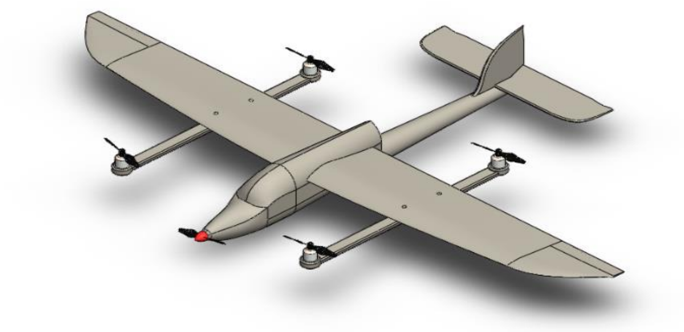


*Figure 2: The overall structure of aircraft*

### *2.3. The Structure Design of Wing*

The wing provides most of the lift of the UAV in fixed-wing flight mode. When the UAV flies in the air, the wing bears the load of the entire weight of the UAV. Considering the change of UAV acceleration, flight attitude and sudden change of airflow during flight, the actual force borne by the wing will exceed the weight of the whole machine. In the process of structural design, the overload factor is set as 2, that is, it is assumed that the force on the wing is twice the weight of the whole aircraft.

The wing structure design requires that the UAV wing should have the minimum structural weight on the premise of ensuring that the structural strength and stiffness meet the requirements. If the strength of the wing is not enough, the wing of the UAV will break off during the flight, resulting in a crash. The stiffness of the wing is not enough, and the wing torsion deformation is too large in the flight process, which will lead to torsion expansion and aileron reverse effect, which will directly affect the aerodynamic, control and stability performance of the UAV, leading to the structural damage or loss of control of UAV and thus crash. But blindly ensure the structural strength and stiffness, the UAV weight is too large, in the case of a certain engine thrust, the UAV will be too heavy and unable to take off. In addition, the structural design of the wing should also take into account the connection of the wing body, the installation of the steering gear, the layout of the rudder line and other factors.

The shear force on the wing is mainly transmitted to the root fin through the web, and then to the wing-fuselage connection from the root fin. So the root ribs and the wing body joints need to be strengthened. Due to the structural disconnection of the wing ribs at the inner and outer wing dividers,

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the longitudinal members turn at this point, which requires redistribution of load and strengthening.

In addition, the wing ribs of the steering gear installation position are connected by the concentrated force of the steering gear. In order to achieve more efficient operation of the steering gear, the steering gear should be closer to the center, so as to determine the position of the steering gear.

### *2.4. The Structure Design of Tail*

According to the overall design requirements of full-size UAVs, it can be known that the flat tail airfoil of fixed-wing UAVs adopts symmetric airfoil. Therefore, the internal structure of the flat tail also needs to be symmetrical up and down, so as to maintain the symmetrical appearance of the flat tail. As the horizontal stabilizer of the UAV, the flat tail provides the pitching moment of the UAV and changes the pitching state of the UAV. During takeoff and flight, the flat tail is used to balance the pitch moment of the UAV and maintain the longitudinal stability of the aircraft. Flat tail structure design can be simpler, as far as possible to reduce the weight of the structure. The flat tail adopts single beam structure, and the front beam is arranged at the maximum thickness of the wing ribs.

## 3. The simulation

This chapter mainly carries out a series of simulation experiments on the designed fixed-wing UAV, including the functions of vertical takeoff and landing, fixed hovering and rectangular flight trajectory control at the same height, so as to verify that the designed UAV has relatively excellent performance. Some data processing is carried out on the generated data, the overall structure is optimized, and relevant conclusions are drawn.

### *3.1. The Simulation of Spot Hover*

The main purpose is to test the attitude, height and position control ability of PID control system and the stability of the whole fuselage.

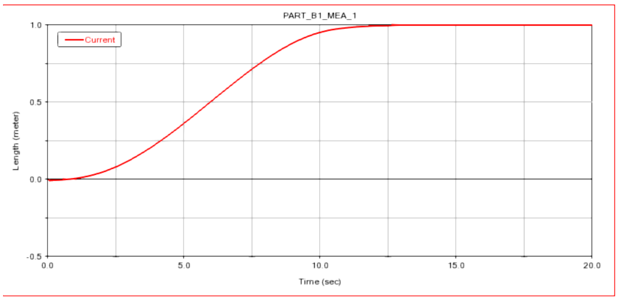


*Figure 3: The simulation of spot hover*

As shown in Figure.3, the vertical takeoff and landing fixed-wing UAV first takes off at an altitude of 0m, and the lift provided by the quadrotor power system makes the overall fuselage rise. At this time, the power provided by the motor is far greater than required, leading to the continuous rise of the aircraft. After that, the PID inner loop control will take effect. The error is caused by the target height and the current height, and the rotation speed of the propeller is regulated by analyzing the error value. It can be seen that when the UAV first took off, it was in an accelerated ascending state, and gradually reached a nearly uniform ascending state when it reached about 3S under the control of P algorithm. In the intermediate process, due to the fast response speed of the control system, the system may be unstable. The closer the UAV is to the target altitude, the more obvious the vibration will be. Therefore, D algorithm is used to control the UAV. When the UAV speed is too fast, D algorithm will offset part of the lift force generated by P algorithm, so as to reduce the vibration of the system.

When the flight reaches about 10s, the UAV is already close to the target altitude. At this time, the rising speed of the UAV should be reduced and reach 0 at the target altitude. However, it cannot be achieved by the PD algorithm alone, because the error can never be eliminated, and without the error, the lift will always exist. Therefore, at this time, algorithm I starts to play a role in regulation, and constantly adjusts the lift force by accumulating errors. It can be seen that the rising speed of the UAV gradually decreases and tends to be stable. At about 12.5s, the lifting force provided by the UAV is equal to its own gravity. It hovers at the target height and then keeps at the same height to achieve stability.

### *3.2. Rectangular Path Tracking Control*

The main purpose is to simulate the aircraft to complete the rectangular path tracking(figure 4), test the flat flight stability of the UAV and the performance of the whole machine, to achieve better control and control.

Through Adams software processing, we can get the plane in xOz plane projection, which can be more intuitive real-time observation of the specific direction of the aircraft, in order to carry out further adjustment and verification in the later stage.

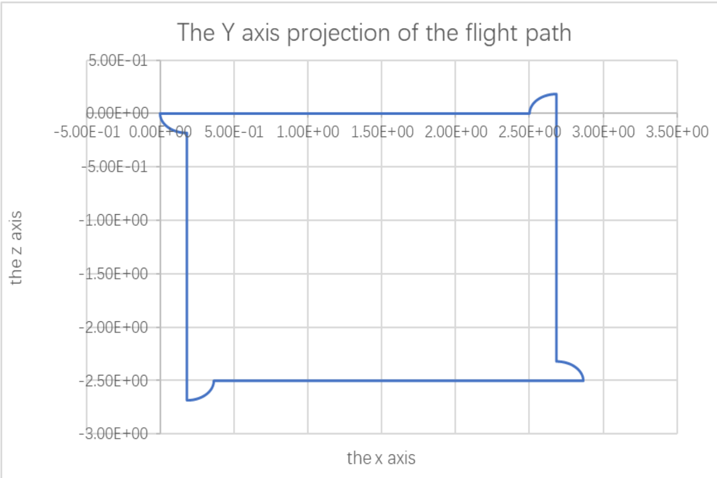


*Figure 4: The result of the rectangular path tracking*

When the UAV realizes vertical takeoff and landing, the UAV maintains the same level altitude and is in a state of equilibrium. At this point, the propeller at the front starts to push, causing the drone to be pushed in the X-axis direction, so the plane begins to level off in the X-axis direction. The UAV first accelerates and then moves at a constant speed around 2S, and then starts to decelerate. When it reaches 2.5E, the deceleration becomes 0. The rotation of the UAV quadrotor will generate torque. When the two pairs of torque are unbalanced, the whole fuselage will be driven to rotate. As a result, the power of the left rotor controlling the UAV is greater than the power of the right rotor, causing the fuselage to rotate 90 degrees before reaching balance again. After that, the UAV began to fly flat in the direction of Z-axis, and also experienced accelerated motion for 2 seconds, then reached uniform motion, and finally stopped when the Z-axis coordinate was 0. Then, the quadrotor continues to work, so that the fuselage rotates 90 degrees and is rebalanced. In 1s, the nose of the UAV faces the negative direction of the X-axis, and the UAV continues to fly flat forward until the X-axis coordinate is 0.

Finally, after 90 degrees of rotation, make the fuselage face the negative direction of Z-axis, and fly flat to the original position. After 90 degrees of rotation, make vertical landing to the ground. The total flight time of each period is 5S, including the acceleration stage, uniform speed stage and deceleration stage. The rotation time of each period is controlled as 1s, and the total theoretical time to complete the rectangular path tracking is 24s.

### *3.3. The Simulation of Motion*

Initially, a simulation was done in SolidWorks, where the UAV is able to take off and rotate 90 degrees. The series of maneuvers were shown in Fig.5.

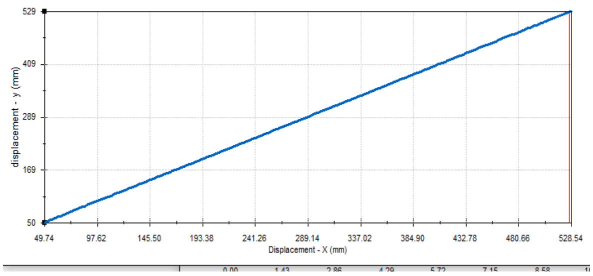


*Figure 5: Motion of the UAV*

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At the earliest stage, the four motors rotate together to generate both forward and upward force to lift the UAV and propel it forward, so that it can follow the trajectory shown in figure 5, which is motion of taking off. During the suspension, the UAV was able to rotate at the given altitude, which is shown in figure 6. The UAV turned 90 degrees. The UAV has four motors, where motor 1 and motor 4 rotate clockwise, the remaining motors rotate anticlockwise. To enable the UAV to rotate clockwise for 90 degrees, the rotate speed of motor 1 and motor 4 increase while that of motor 2 and motor 3 decrease, which creates net torque. This can keep the UAV at the same altitude while the UAV is rotating.

When it comes to the lifting force, the wight of power system, structure weight of UAV and effective load weight are taken into account. All these forces acting together enable the UAV to take off. This can be concluded in a equation as following.

$$W_{lift} = W_{power\ system} + W_{structure} + W_{effictive\ load} \quad (1)$$

As for the force enabling the UAV to move forward, we considered the air resistance so we can derive the formula for forward force needed.

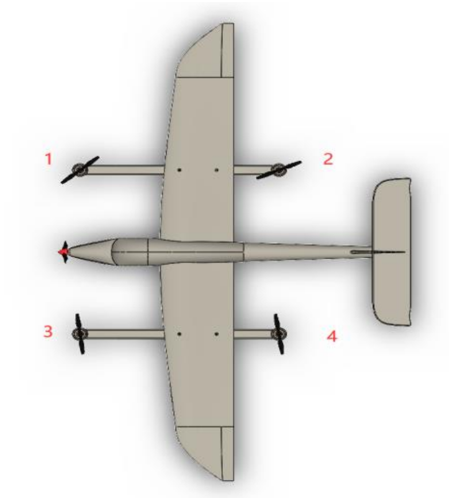


*Figure 6: Four motors of the UAV are illustrated, where motor 1 and motor 4 rotate clockwise and motor 2 and motor 3 rotate anticlockwise*

## 4. Conclusions

In this paper, we clarify the concept of vertical takeoff and landing technology. We complete the structure design and parameter determination of UAV, and the modeling is completed in SolidWorks. After the overall modeling is completed, the classical PID control theory is used to control the UAV. Complete the mechanical analysis in Adams, realize the simulation of vertical takeoff and landing under the simulated gravity condition, and realize the concrete simulation of rectangular path tracking, verify the feasibility and rationality of the designed UAV scheme.

Finally, in future research work, the classical PID control theory is used in the design method of the control system of vertical take-off and landing fixed-wing UAV. Although the ideal effect has been achieved, the accuracy and stability of the classical PID control may not reach the ideal effect with the deepening of the complexity of the flight mission and flight environment. Therefore, try to apply other intelligent control algorithms and so on.

In this paper, the existing quadrotor motor and the recommended propeller are directly used. In order to improve the working efficiency and service life of the rotor part, the dynamic design and separate CFD analysis of the blade can be carried out. The influence of rotor wake on fixed wing can be analyzed by CFD method to optimize the relative position of rotor and wing.

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