Research on Aerodynamic Characteristics of Composite powered Unmanned Airship

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Abstract. The main structure of the composite powered unmanned airship is consists of airbags and four-rotor system, which airbag increases the available lift, and has more advantages in terms of load and flight when compared with the traditional four-rotor. In order to compare the aerodynamic performance of the composite powered unmanned airship and the traditional four-rotor, the SIMPLE algorithm and the RNG k-epsilon model method are be used. The energy consumption of the composite powered unmanned airship is lesser than the traditional four-rotor under the same load and range was found.

1. Introduction

Today, four-rotor craft has become more common in our field, which covering the use of aerial photography, aerial surveys, plant protection and flight experience. Because of its superior handling performance and stability, especially in the field of aerial photography has made the industry's favorite. But due to the battery capacity and its own structure, the traditional four rotor is not good enough in the flight and load than other types of aircraft [1]. To this end, the industry developed a variety of improved programs, such as adding airbag to provide an additional upward forcedly[2]using the airbag in the four-rotor structure, which greatly increasing the payload of the aircraft. Due to the whole of four rotor structure hanging under the airbag that the overall center of gravity of the aircraft move up, Resulting in the aircraft has some difficulties to control In the flight. In order to solve this problem, the connection of traditional four-rotor and airbag has been improved [3].

In order to analyze the performance advantages of the improved aircraft, choose the way that Compare the energy consumption of the two kinds of aircraft under the same load and range to see which one is better.

2. Model design

2.1. Three-dimensional model

The main structure of the compound powered unmanned airship includes airbags and four rotor systems. The traditional four rotor is made up of two carbon fiber rod as the main structure which contact under each other. Each carbon rod at both ends of the installation of a rotor motor used to provide lift, and the concrete model is shown in Fig1. The compound powered unmanned airship has been added a spherical airbag on the basis of the traditional four-rotor system, and the geometric
center of the whole four-rotor structure coincides with the geometric center of the airbag. The concrete model is shown in Fig2.

The main geometric parameters of the study object are as follows: Four rotor shaft arm is round bar, which length is 5m, and outer diameter is 50mm. The vertical distance between the upper and lower shafts is 52mm, the airbag is a balloon which diameter is 3.6m. The coordinates of the center of the rotor in the geometric center of the overall structure are the coordinates of the origin:(2460 mm, 0, 14 mm), (-2460 mm, 0, 14 mm), (0, 2460 mm, 66 mm), (0, -2460 mm, 66 mm).

The two leaves "2880" model rotor is used to calculate, which diameter of the rotor is 711.2 mm, and pitch is 20.32mm. The rotor is used more in the market, that experimental data more comprehensive, and easy to carry out analytical research. For easier to calculate the following assumptions:

1. In all states, the rotational speed of the four rotors is the same;
2. The flow is constant and stable [4];
3. Does not take into account the inclination of the torque generated by the problem;

![Figure 1. The model of the traditional four-rotor](image1)

![Figure 2. The model of Composite powered unmanned airship](image2)

2.2. Formula introduction

Due to the special principle of the rotor structure flight, using the differences tilt angles of rotor to produce different forward pull force. So different tilt angles represent different flight speeds. As a result of the flight speed increases, the air resistance increases. In each flight inclination corresponds to a flat speed $V$, at the speed of the aircraft forward direction of the resultant force is zero, do uniform motion. The aircraft is flying in an "X" flight and the angle between the XY plane of the body coordinate system in the flight state and the XY plane in the spatial coordinate system is the angle of inclination, denoted by the angle $\theta$. 
In order to ensure that the load of the two aircraft is the same during the flight, the air lift of the composite powered unmanned airship is calculated [5]. The airbag is filled with helium that provides buoyancy. The formula is as follows:

\[ F_{He} = K_{He} V \]  

(1)

\[ M = \rho S \]  

(2)

\[ F_r = F_{He} - Mg \]  

(3)

- \( F_{He} \): The total buoyancy provided for helium;
- \( K_{He} \): Is the unit volume lift coefficient of helium, here take \( \frac{10.35N}{m^3} \);
- \( V \): The helium volume;
- \( M \): The quality of airbag skin;
- \( \rho \): The density of the skin material;
- \( S \): The surface area of the skin (here selected imported Kevlar matrix polyurethane coating material [6], the surface density is \( \frac{240g}{m^2} \));
- \( F_r \): The net lift of the airbag;
- \( g \): Gravity acceleration, here take \( \frac{9.8N}{kg} \).

The airbag provides a net lift of 157 N by calculated, so the combined powered unmanned airship rotor under the same load provides a lift of 157 N smaller than that of the traditional four-rotor. The simple thrust method is used to determine the flight speed of the aircraft. Increase the flow velocity, and obtain the rotor speed and flow velocity that satisfy the flat fly condition under the inclination angle, by simulating the iterative method. The flow velocity is the flat speed. The formula for the flight conditions is as follows:

\[ \begin{align*}
T &= D \\
L &= W
\end{align*} \]  

(4)

- \( T \): The aircraft forward thrust;
- \( D \): The flight state resistance;
- \( L \): The aircraft to lift force;
- \( W \): The overall gravity of the aircraft.

2.3. Calculation method

The RNG k-epsilon model is an improved version of the k-epsilon turbulence model. The RNG k-epsilon considers the low Reynolds number flow viscosity and improves the high Reynolds number properties of the standard k-epsilon model, taking into account the Turbulence swirl, and therefore applicable to the low value of Reynolds number and a strong vortex of the numerical simulation.

The SIMPLE algorithm is used to separate the velocity component and the pressure equation. The second order upwind scheme is used for the interpolation of the convective terms. The node-based Green-Gaussian method is used to interpolate the diffusion terms. The multi-reference coordinate system model (MRF) is used to numerically solve the three-dimensional N-S equation [7].
3. Results and Analysis

3.1. Verification of the calculation method
By comparing the CFD calculation data and experimental data to verify the reliability of the method. The net tension of the rotor at different speeds in two cases is compared. As can be seen from Figure 3, the simulation model calculation data and specific experimental data look similar. Some of the minor differences in the latter data are due to the fact that the density or viscosity coefficient is somewhat different under experimental conditions. It can be concluded that the calculation method is correct and reliable and can be used to study the aerodynamic characteristics of the physical model of the aircraft.

![Figure 3. CFD calculation data and experimental data comparison chart](image)

3.2. Analysis and Research on Parameters of Parameter
The experimental method is carried out by studying the difference between the flight speed and the rotor speed of the two aircraft at the same flight angle, the same load and range. Assuming that the total load is 400 N, the lift required for conventional aircraft is 400 N, and the lift for the combined powered unmanned airship is 243 N. Using the above calculation method, the two kinds of aircraft were simulated and analyzed to determine the energy consumed by the two aircraft in the horizontal flight state when the angle of inclination is 20°.

By calculating the current consumption at a motor rotation speed, the total energy dissipation under the load \( W \) and the range \( S \) is obtained. From formula (5), it is concluded that the total energy consumption is proportional to \( \frac{IU}{WV} \) in a certain voyage, where it is defined as "the energy consumed per unit load"

\[
\begin{align*}
E &= UIt \\
S &= Vt
\end{align*}
\Rightarrow E = \frac{I}{V}US
\]

\( E \): The motor power consumption;
\( U \): The motor operating voltage;
\( I \): The motor operating current;
\( S \): The distance;
\( V \): The flat speed;
In order to know the operating current of a motor at each speed, the motor is tested at constant voltage to obtain the current curve when the voltage is 44.8V, as shown in Figure 4. When the motor operating voltage is constant, the motor current increases with the rotor speed, and each motor speed corresponds to a working current. Combined with the formula (5), it can be drawn that the greater of the flying speed, the less of the total energy consumption.

Test the size of the lift of the traditional four-rotor at different flight speeds, at the rotor speed of 4500rpm. Observe the changes in lift. It can be seen from Fig. 5 that the total lift of the traditional four rotor decreases with the increase of the flight speed when the inclination angle is constant, which is in accordance with the law of the maximum static tension of the rotor [8].
Figure 6. Performance characteristics of composite powered unmanned airship

![Composite powered unmanned airship](image1)

Figure 7. The pressure nephogram and streamlines of the composite powered unmanned airship

![Pressure nephogram and streamlines](image2)

As can be seen from Figure 6, when the composite powered unmanned airship at a certain angle, as the flight speed increases, the total lift increases, this is different from the traditional four-rotor. Figure 7 shows the pressure reprogram and streamlines of the composite powered unmanned airship at the Y=0 section, it can be seen that the flow is affected by the rotor, so the position of the fore stagnation point of the airship is lowered when the airship flies forward, this made the airflow in the upper half of the composite powered unmanned airship is faster when the airflow through the composite powered unmanned airship, then the pressure drop causes the airbag produce lift, which allows the composite powered unmanned airship to carry more loads[9].

Based on the analysis of the flight characteristics of the two aircraft and the adjustment of the flight speed and the rotor speed, the flight speed and the corresponding speed of the minimum energy consumption under the load requirement are obtained. As the maximum speed of the selected motor is 5280 rpm, the rotor speed is selected between 0 and 5000 rpm for easy energy consumption calculation. As the traditional four-rotor with the increase in flight speed lift reduced, so under a certain load there must be a maximum flight speed to ensure the minimum energy consumption. So the minimum energy consumption of the selection point should be found in the test speed to meet the lift when the maximum flight speed of 400N.
According to the data analysis in Fig. 8, when the load is 400N, the traditional four-rotor reaches a maximum flight speed of 12.9m / s at a speed of 5000rpm, and the power consumption per unit voyage is 0.434J / MN. Due to the flying characteristics of the compound powered unmanned airship, at the inclination of 20 degrees, it is the point where the resultant force satisfies the load and satisfies the horizontal direction, that is, the optimal flat speed. By the iterative calculation, the optimal flying speed of the composite unmanned airship is 6.6m/s at an inclination of 20°, and the corresponding speed is 3250rpm. The electricity consumed under the unit voyage is 0.246J / MN < 0.434J / MN. So in this flight state, the composite power unmanned airship energy efficiency is higher.

4. Conclusion
(1) The composite powered unmanned airship is higher in energy efficiency than the traditional four-rotor in the same load.
(2) By the rotor air flow, the composite power unmanned airship can get additional lift.

Acknowledgments
This work was financially supported by the National Natural Science Foundation of China (51266012), And Jiangxi Province Graduate Innovation Fund Project (YC2016-S352).

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