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Study on the Effect of Tilting-Rotor Structure on the Lift of Small Tilt Rotor Aircraft

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Abstract: In this paper, the influence of the tilting-rotor structure parameters on the aerodynamic characteristics of a small tilt rotor unmanned aerial vehicle (UAV) is studied. The simplified model of tilt rotor unmanned aerial vehicle (UAV) is established by using SolidWorks software, and the model is divided into unstructured grid by ICEM software. Finally, set the corresponding boundary conditions in the FLUENT software and then simulated. By simulating the flight state of the tilt rotor unmanned aerial vehicle (UAV) in the fixed wing mode, the lift-drag aerodynamic characteristics of the aircraft in that flat flight mode are obtained. On the other hand, researched the effect of the tilting angle of the tilting-rotor mechanism, the size of the multi-rotor structure (the distance of the tilting-rotor mechanism from the fixed wing), and the rotor installation distance of the coaxial twin propeller mechanism on the complex flow field between rotor and fixed wing. Obtained some meaningful conclusions, which are useful for the future design of the small tilt rotor unmanned aerial vehicle.

Key Words: Tilt rotor unmanned aerial vehicle; Tilting-rotor structure; Simulation; Aerodynamic characteristics

1 INTRODUCTION

The tilt rotor aircraft is a new configuration principle of the aircraft, which is a new concept between the rotor aircraft and fixed-wing aircraft. When the tilting-rotor system components are in the vertical position, the tilt rotor aircraft is similar to the multi-rotor aircraft, which can realize the functions of hovering, side flying, rear flying, vertical takeoff and landing. When the tilting-rotor system components are in the horizontal position, rotorcraft is equivalent to fixed-wing aircraft, which have the big flight envelope for its high-speed and long-range flight performance [1]. Foreign research on tilt rotor aircraft started earlier, is now to the engineering stage [2-3]. Domestic research on tilting rotorcraft started late, and most of the research focused on rotor response and inter-rotor airflow interference [4]. In recent years, with the development of Computational Fluid Dynamics(CFD) methods, domestic and foreign workers have done a lot of research. In [5], the performance and the aerodynamic interference effect of the tilt rotor aircraft's overweight state are analyzed by the combination of experiment and CFD. In the literature [6], the numerical simulation of the flow field in the forward flight and the quasi-normal transition state of the tilting rotorcraft is carried out. The aerodynamic interference of the front rotor to the rear rotor and the aerodynamic force of the front and rear wing are analyzed. However, the study of [5-6] is directed only to individual rotors, and does not involve aerodynamic interference between the rotor and wing. The literature [7] uses the free wake method to calculate and analyze the rotor performance. In the literature [8-11], the CFD method is used to analyze the rotor-wing flow field, and the flow field between the rotor, the wing and the fuselage is analyzed in detail, but the influence of the rotor flow field on the wing is not studied emphatically.

In this paper, the aerodynamic characteristics of tilting rotorcraft in different flight states are studied by using FLUENT as the calculation platform. By analyzing the aerodynamic lift and resistance of the aircraft, the optimal aerodynamic characteristics of the aircraft in the flat flight state was got. And the quantitative effects of the tilting-rotor structure on the aerodynamic characteristics of the aircraft are summarized by a large number of numerical simulation results.

2 MODELING AND SIMULATION

2.1 Computational model and grid generation

In this paper, the problem of aerodynamic interference between the tilting rotorcraft's tilting rotor system and the fixed wing is studied. In the tilt transition process of the tilting rotorcraft, only two pairs of front end coaxial twin propeller mechanism are tilted and produce air interference with the fixed wing. Therefore, in order to simplify the simulation model, the overall model of tilting rotorcraft was replaced by the model of two pairs of coaxial twin propeller mechanism plus fixed wing. And in order to reduce the difficulty of simulation, the flow field of coaxial twin propeller mechanism is simplified into a cylindrical uniform velocity flow field. The simplified model structure is shown in Figure 2-1.

The model is divided into unstructured grid. And the whole calculation model used the origin of the simple physical model of tilting rotorcraft as the origin of the model.

Because the computational model was a simplified model of the rotor and the fixed wing, the grid of the rotor (cylinder) and the wing calculation domain was denser. In order to show the details of the flow field clearly, the grid of the entire large computational domain was also more intensive, which has 1.3 million grids. The calculation grid of the rotor/wing simplified model is shown in Figure 2-2.

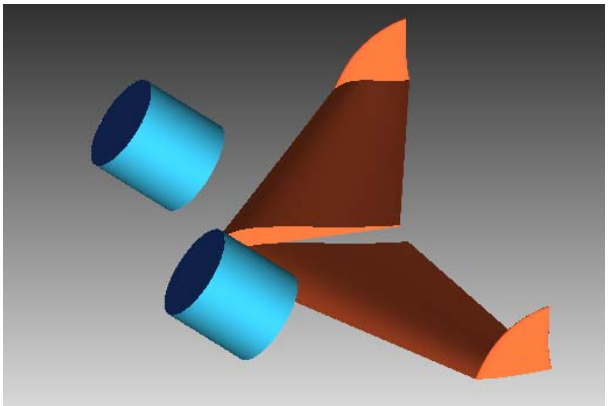

Figure 2-1 Simplified model of tilting rotorcraft

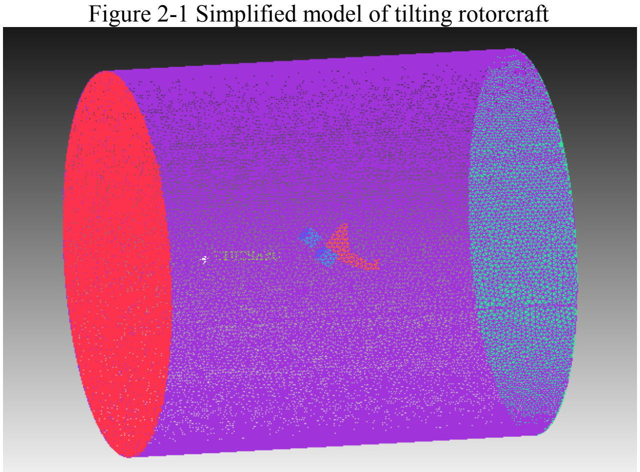

Figure 2-2 Calculation grid of rotor/wing simplified model

2.2 Boundary condition settings

The generated grid file was imported FLUENT solver to solve, and the specific solution was as follows:

1) Check the grid. Click check, check the grid quality, to ensure that the grid volume is positive;
2) Adjust the model size. Click Scale, the unit of the model will be adjusted to mm;
3) Select the calculation model. Select the standard k-ε model to calculate;
4) Set the fluid material properties. Density set to ideal gas, material set to air;
5) Boundary condition setting. Set the IN1 inlet speed for the aircraft flight speed, IN2 inlet speed for the experimental measured downwash flow speed of the coaxial twin propeller, OUT set pressure-outlet, the other side set to wall;
6) Convergence monitoring. The monitoring parameters are all changed to 0.0001;
7) Initialization. Click Standard Initialization, the calculation area select all-zone;
8) Set the number of iterations 500 times, solve.

3 CALCULATION RESULTS AND ANALYSIS

3.1 Lift -drag characteristics of tilt rotor aircraft

The basic flight performance of the aircraft depends to a large extent on the aerodynamic characteristics of the aircraft. In a certain power plant conditions, excellent pneumatic layout is the important conditions of obtaining good aerodynamic characteristics and ensuring the aircraft technical performance requirements.

The most important aerodynamic characteristics that determine aircraft flight performance are: The maximum lift-drag ratio of the tilting rotorcraft K_{max}, the influence of change of angle of attack α on lifting characteristics, maximum lift coefficient C_{ymax} and so on.

The aerodynamics R acting on the tilting rotorcraft can be decomposed into lift Y, resistance Q and lateral force Z , and can be expressed by the corresponding lift coefficient $\mathbf{C_y}$, drag coefficient $\mathbf{C_x}$ and side force coefficient $\mathbf{C_z}$, as formula (1) ,(2) and (3).

$$Y = C_y \frac{1}{2} \rho \upsilon^2 S \tag{1}$$

$$Q = C_x \frac{1}{2} \rho \upsilon^2 S \tag{2}$$

$$Z = C_z \frac{1}{2} \rho \upsilon^2 S \tag{3}$$

In the above formula, **ρ** was the air density, **υ** denotes the flying speed of the airplane, and **S** denotes the wingspan area of the airplane. The coefficients are usually complex functions such as the aircraft configuration, the smooth surface condition, the deflection angle of the control surface **φ**, the flow conditions (aircraft angle of attack **α**, side slip angle **β**, Mach number **M**, Reynolds number **Re**) and engine operating status (indicated by throttle position $\boldsymbol{\delta_p}$). It is generally impossible to write an analytical expression, but can be confirmed through the wind tunnel test, test flight or the use of engineering estimates. When the aircraft has no slip flight (β=0), the side force coefficient C_z is zero, this time, the lift coefficient C_y and drag coefficient C_x can be expressed as formula (4) and (5).

$$C_y = f_1(\alpha, \varphi, M, Re, \delta_p) \tag{4}$$

$$C_x = f_2(\alpha, \varphi, M, Re, \delta_p) \tag{5}$$

In the case of constant flight height and throttle position (δ_p), regardless of the effect of the flat tail deflection angle φ on the lift resistance characteristic (the flat flight mode of the tilting rotorcraft is flying wing structure, without flat tail), and the change of the Reynolds number is negligible at a low speed. So, the expression of the lift coefficient C_y and the drag coefficient C_x can be simplified as formula (6) and (7).

$$C_y = f_1(\alpha, M) \tag{6}$$

$$C_x = f_2(\alpha, M) \tag{7}$$

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