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Investigation of Dynamics and Control for Unmanned Helicopter in Vertical Flight Mode

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A B S T R A C T

Helicopters are used for various purposes due to their superior ability to fly in all directions and vertical takeoff. Unmanned helicopters are controlled by automatic devices on board or by remote control. This article presents a method for determining the flight and control parameters of unmanned helicopters in hovering and vertical takeoff and landing modes. The motion of the helicopters is investigated by solving a system of differential equations.

Keywords: Unmanned helicopters; vertical flight mode; thrust force; flap angle.

1. Introduction

Unmanned helicopters (UHs) are a type of aircraft that can perform many functions, both in military and civilian fields. UHs can be used for monitoring high-voltage power lines, filming, taking photos, monitoring forest reserves, etc… In military it is used for reconnaissance, rescue, and battlefield observation.

The design and manufacture of UHs in Viet Nam has not been invested in due to various reasons, including researching the aerodynamics and dynamics of UHs is unsystematic. Therefore, studying the basic motion of UHs in the most basic mode, which is vertical and hovering at a certain altitude before descending vertically, is the initial step for more comprehensive and in-depth research on the design, manufacture, and control of UHs in the future.

2. Methodology

2.1. Calculation of the dynamics of the unmanned helicopter in the vertical flight mode.

Considering a rotor blade of the unmanned helicopter in the vertical flight mode with the force diagram (Figure 1). The blade element area is dr.b (dr - the radius increment of the blade, b - the blade chord). The collective angle, which is controlled by the flight control computer, is denoted by θ. The angle between the direction of the airflow and the plane of the rotor disk is denoted by φ, also known as the attack rangle of the blade [1], [2]:

According to the diagram in Figure 1, when replacing the symbol V_C with V, the attack angle of the blade φ is determined by the formula:

$$\varphi = \text{artg}(\frac{V_i+V_y}{\Omega.r}) \quad (1)$$

The actual angle of attack of the blade element is:

$$\alpha = \theta - \varphi \quad (2)$$

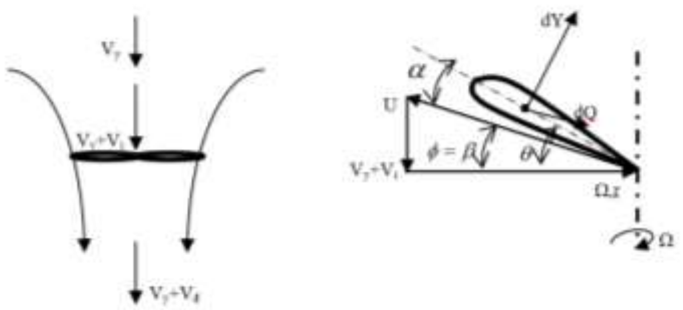

Figure 1. Diagram for calculating the dynamic flight of a helicopter in vertical flight mode.

The elements of lift and drag forces on the rotor blade element are:

$$dY = c_y^{\alpha}.\alpha.\frac{1}{2}.\rho U^2.b.dr; \quad dQ = c_x.\frac{1}{2}\rho U^2.b.dr \qquad (3)$$

where: $U = \sqrt{(V_y + V_i)^2 + (\Omega.r)^2}$

From the force distribution diagram in Figure 1, the thrust force element dT of the rotor blade is the difference between the lifting force element dY and the drag force element dQ along the vertical axis (axis of rotation of the rotor blade):

$$dT = dY.\cos\varphi - dQ.\sin\varphi \qquad (4)$$

The resultant thrust force of rotors are:

$$T = N.\int_{R_0}^{R} dT$$

where R_0 - is the inner radius of the blade root, R - the outer radius of the blade tip.

The system of equations of the motion of a helicopter in a vertical plane is given by:

$$\begin{cases} m\frac{dV_y}{dt} = T - Q_T - G \\ \frac{dH}{dt} = V_y \end{cases} \qquad (6)$$

Where:

T- thrust of the blade

Q_T- body drag force, $Q_T = c_T\frac{1}{2}\rho.V_y^2 S_T$;

c_T- body drag coefficient

S_T- frontal surface area;

G- weight of the helicopter.

The additional equation for the induced velocity V_i caused by the rotor blades is determined based on the theory of conservation of momentum in relation to the thrust force T, as follows [3]:

$$V_i = -\frac{V_y}{2} + \sqrt{\frac{V_y^2}{4} + \frac{T}{2.\rho.A}} \qquad (7)$$

We observe that the system of motion differential equations (6) and the additional equation (7) will consist of 3 equations with 3 unknowns: altitude H, vertical takeoff speed V_C, and induced velocity V_i. Therefore, it can be solved.

In order for the calculation process to be continuous, we use a numerical method to determine the combined velocity field U of the helicopter and transmit the data through the software to solve the system of motion differential equations, not determined through V_i induced velocity by analytical calculation. The determination of velocity U by numerical method is performed using either the discrete vortex method supported by C++ software [4] or the finite volume method supported by ANSYS.CFX software [5].

2.2. Helicopter Status Control

According to the theory of helicopter control, the collective pitch control through altitude and airspeed takes the form [3]:

$$\theta = k_H(H_{CT} - H) - k_V.V_y \qquad (8)$$

The collective pitch angle and the blade pitch angle:

$$\theta = \theta_x - k.\beta \qquad (9)$$

Where θ_x is the initial twist angle, and β is the flap angle of the helicopter rotor blade.

In equations (8) and (9), k_H, k_V are the control coefficients based on altitude and airspeed, k is the flap compensation coefficient, and H_{CT} is the altitude, which is pre-calculated so that when the actual altitude H (provided by the satellite positioning system on the helicopter) will follow it during control. The coefficients k_H, k_V are selected based on experimental planning data for an certain unmanned helicopter.

3. Results and Discussion

3.1. Quarter helicopter model data.

A certain unmanned helicopter was selected for investigation, with the following data:

- Rotor radius: R = 0.775 m
- Blade chord: b = 0.058 m
- Angular velocity: Ω = 20 rad/s
- Projected body area: $S_T = 0.15\ m^2$
- Number of rotor blades: N = 2
- Helicopter mass: m_{tt} = 8.5 kg
- Rotor blade moment of inertia: $I_V = 0.038\ kgm^2$
- Lift coefficient derivative: $c^{\alpha}_{y} = 0{,}09\ rad^{-1}$
- Drag coefficient: c_x = 0,024
- Body drag coefficient: $c_T \approx 0{,}2$
- Flap Compensation coefficient: k = 0.2
- Altitude control coefficient: k_H = 0.006 rad/m
- Speed control coefficient: k_V = 0.002 rad.s/m

3.2. Simulating the aerodynamics of a helicopter.

Simulating the aerodynamics of helicopter rotors is conducted using the non-steady state unsteady vortex method [1]. The simulation result of the velocity field around the helicopter rotor blades is described in Figure 2.

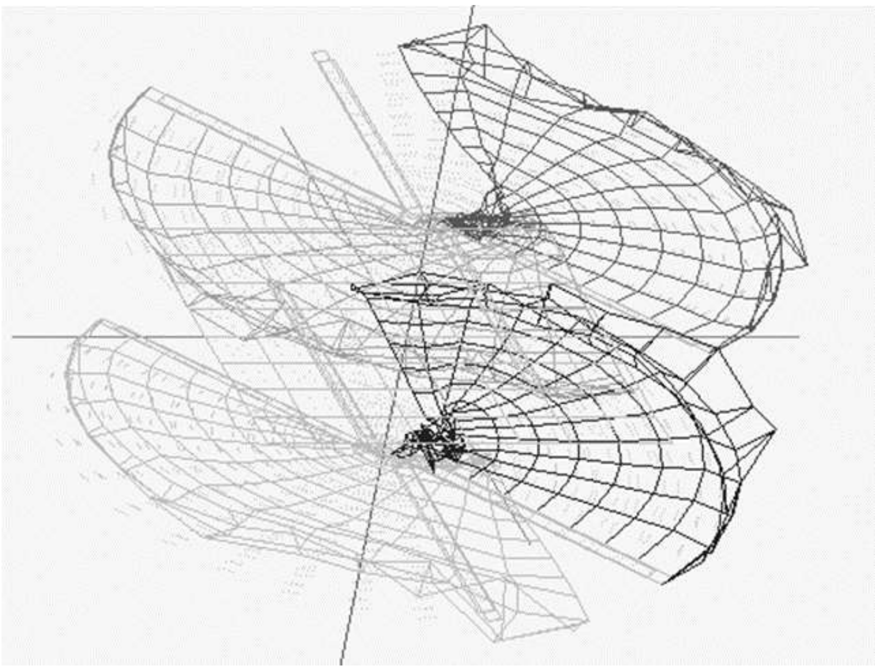

Figure 2. Velocity field around rotor blades.

3.3. Results of helicopter control in vertical flight mode

During the process of vertical flight, the thrust force of the blades continuously increases as the collective pitch angle θ (controlled by the pilot) increases to ensure that the helicopter reaches the necessary altitude. Meanwhile, the flapping angle (β) of the rotor blades changes very little and is almost linear with the change in collective pitch angle. This can be explained by the fact that during vertical flight, the rotor blades of the helicopter hardly flap due to the gradual and even ascent (figure 3).

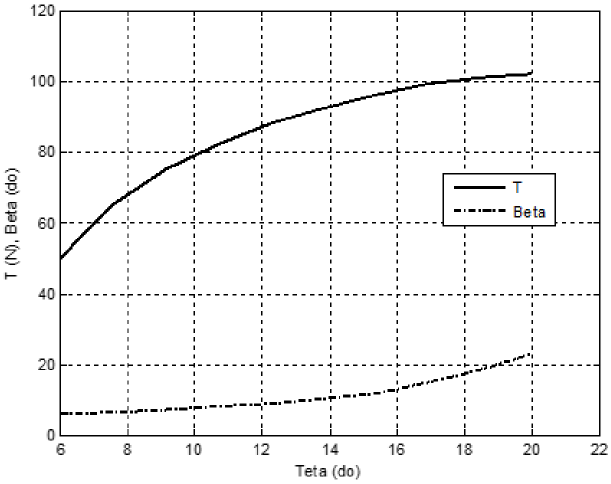

Figure 3. Changes in thrust force and flap angle with collective pitch angle.

The helicopter's state (altitude, speed) is determined by the system of motion equations (7) and controlled by the equations (8), (9) with input data from the investigated helicopter model. The helicopter's ascent trajectory and flight program trajectory are shown in Figure 4. The variation of V_y, collective pitch angle (θ) of rotor blades over time are presented in Figures 5 and 6.

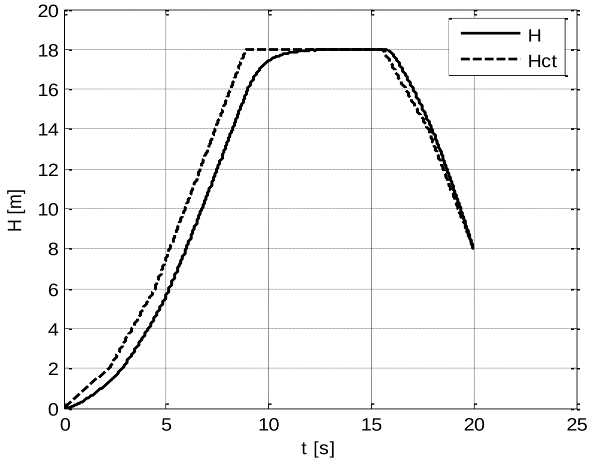

Figure 4. Changes in altitude deviation from program altitude.

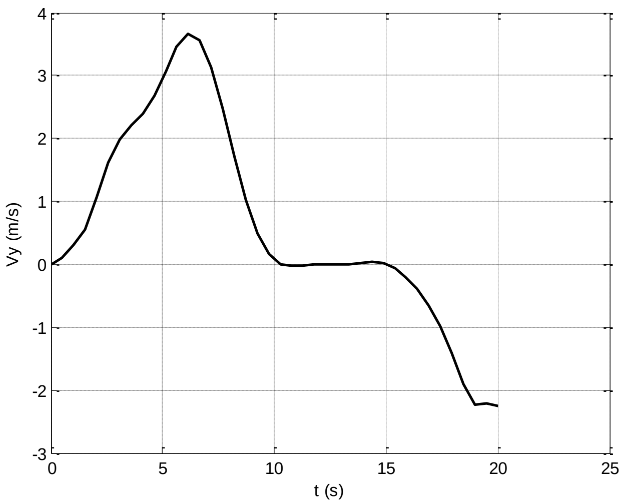

Figure 5. Changes in V_y

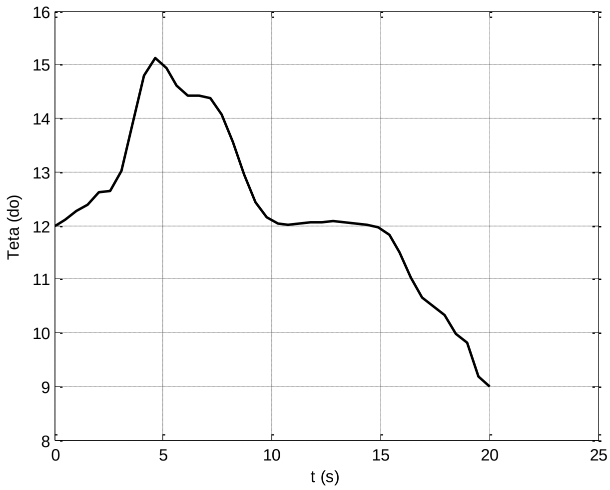

Figure 6. Changes in collective pitch angle over time

In summary:

1. The controlled altitude of the helicopter is calculated according to the pre-selected altitude; For vertical flight, the airspeed of the helicopter gradually increases. When reaching a stable hover height (H=const), the airspeed of the helicopter decreases to 0. During the process of reducing altitude, the airspeed of the helicopter decreases gradually (Vy<0). Therefore, the results show good agreement with the theory.

2. The variation of the collective pitch angle of the rotor blades are selected for investigation is consistent with the Helicopter Flight Control Law in vertical flight mode. To fly up, the collective pitch angle must be increased (increase throttle and increase the area of the rotating plane) to increase the thrust force. At a certain point, when the upward speed decreases, the collective pitch angle is also controlled to decrease gradually. When reaching a certain height (H=const), the collective pitch angle reaches a constant value (θ =const) during stable hover time to keep the rotor working stably. When reducing altitude, the collective pitch angle must be decreased to reduce the thrust force of the rotor.

CONCLUSION

The results of the study of the dynamics and control of the unmanned helicopter model show that the thrust force of the rotor increases when the collective pitch angle increases and the flap angle also increases. The change of the trajectory of the helicopter in vertical flight mode, the pitch angle, and the flap angle of the rotor change according to the Helicopter Flight Control Law.

The motion and control model of the helicopter has only considered the rotor blades as the main control object. The influence of the helicopter body is only considered as the projected body drag by the wind tunnel. To have more complete results on the motion and control of the helicopter, the dynamics of the whole helicopter (with body, tail rotor, engine) and the body should be studied, and these are the issues for further research.

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