2023_"ShuWei Cup"

Problem A：Modeling and Optimization Control Issues of Compound Helicopter

A. Problem Background

Helicopters possess flight capabilities such as vertical takeoff and landing, making them widely applicable in fields such as reconnaissance and transportation. The configuration of traditional helicopters causes the rotor blades to be affected by shock waves during high-speed flight, making stable flight difficult. In order to retain the flexible flying capability of helicopters while developing their high-speed flight capability, the design of compound helicopters, which combine fixed wings with rotors, has become an essential direction for development.

Coaxial helicopters are a typical type of compound helicopter. This configuration mainly consists of four power components: coaxial rigid rotors, propeller thrusters, and horizontal and vertical tails. The centers of the propeller thrusters and horizontal and vertical tails are all located on the flying machine fuselage's symmetry plane. The flying machine's attitude angles refer to the roll angle ϕ, pitch angle θ, and yaw angle ψ during flight, and the corresponding moments are known as roll moment, pitch moment, and yaw moment (as shown in Figure 1). The influences of the four power components on the flying machine's attitude angles are as follows: 1) The aerodynamic moment generated by the coaxial rigid rotors can be approximated as a function proportional to the air density ρ, rotor disc area, and rotor blade tip velocity, the positive scale factor is called the rotor moment factor. 2) The propeller thrusters generate thrust and rotational moment through rotation. 3) The horizontal tails are equipped with elevator control devices, which adjust the relative angle of the horizontal tails to provide pitch moment. This moment is proportional to dynamic pressure, horizontal tail area, and the lateral distance between the horizontal tail and the center of mass, with the proportionality coefficient known as the horizontal tail moment coefficient. 4) Similar to the horizontal tails, the vertical tails provide yaw/roll moment by adjusting the relative angle by installing a rudder control device. This moment is proportional to dynamic pressure, vertical tail area, and the lateral/longitudinal distance between the vertical tail and the center of mass, with the proportionality coefficient known as the vertical tail moment coefficient.

The maneuverable parts of a composite helicopter are as follows: (1) Coaxial rotor overall distance u_c, (2) Coaxial rotor differential total distance u_{cd}, (3) Coaxial rotor longitudinal cycle pitch u_e, (4) Coaxial rotor lateral cycle pitch u_a,(5)Propeller thruster operating capacity u_t, (6) Elevator deflection values u_{eh}, (7) Rudder deflection values u_{av}. Depending on the helicopter's flight speed, in the low-speed mode (generally referring to speeds below 85 meters/second), attitude angle control is realized mainly by coaxial rotor and propeller thrusters. In the high-speed mode (generally referring to speeds above 100 meters/second), attitude angle control is mainly realized through propeller thrusters, elevators, and rudder.

An example of a coaxial composite helicopter prototype is available, and some of the aerodynamic coefficients and airframe parameters of this vehicle have been obtained through wind tunnel experiments, as shown in Appendix I.

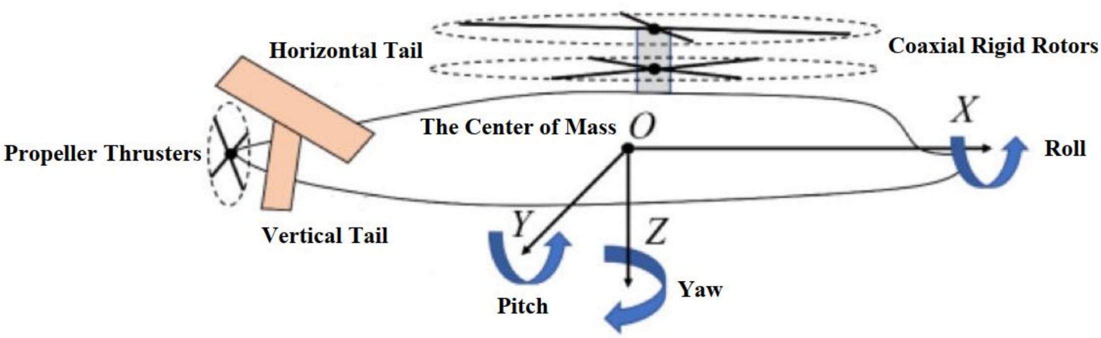

Fig.1. Coaxial helicopter configuration and roll, yaw, pitch schematic diagram

B. Title Data

Refer to Appendix I.

C. Issues To Be Addressed

1.Considering the given parameters, establish the expression for the pitch moment of the compound helicopter and develop a model for pitch angle variation. Please provide the attitude angles of the flying machine at

5s, 10s, and 20s (initial flight altitude of 3000 meters, flight speed forward component 80 m/s, vertical ascent component 2 m/s, $u_c = 0$ degree、$u_{cd} =- 2.1552$ degree、$u_e =- 3.4817$ degree、$u_a =- 2.0743$ degree、$u_t = 0$ degree、$u_{eh} =- 9.0772 \times 10^{-7}$ degree、$u_{av} = 4.1869 \times 10^{-7}$ degree)

2. Based on the title given parameters, establish the expressions for the compound helicopter's roll, pitch, and yaw moments and develop a model for the variation of attitude angles. Please provide the attitude angles of the flying machine at 5s, 10s, and 20s (initial flight altitude of 3000 meters, flight speed forward component 80 m/s, vertical ascent component 0.2 m/s, $u_c = 0$ degree、$u_{cd} =- 2.1552$ degree、$u_e =- 3.4817$ degree、$u_a =- 2.0743$ degree、$u_t = 0$ degree、$u_{eh} =- 9.0772 \times 10^{-7}$ degree、$u_{av} = 4.1869 \times 10^{-7}$ degree)

3. Based on the maneuvering characteristics of helicopters during low-speed and high-speed flight, designing the magnitude of the maneuvers of each component to satisfy the vehicle's level-flying mission (zero attitude angle)for the aircraft (initial flight altitude of 3000 meters, flight speed forward component of 80 meters/second, vertical ascent component of 0.2 meters/second; initial flight altitude of 3000 meters, flight speed forward component of 180 meters/second, vertical ascent component of 0.2 meters/second).

4. Considering the helicopter's acceleration maneuver task, where the

flight speed forward component increases uniformly from 80 meters/second to 180 meters/second within 20 seconds (assuming the forward acceleration is provided solely by the propeller booster), please design the dynamic values of each control input to achieve both forward acceleration and level flight (zero attitude angle) for the aircraft, taking into account the maneuvering characteristics of the helicopter during low-speed and high-speed flight (initial flight altitude of 3000 meters, flight vertical ascent component rate of 0.2 meters/second).

D. Online Resources and References Related to The Question

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