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Performance Characteristics Analysis and Modeling of Near Space Parachute UAV

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Aerodynamic layout diagram of UAV

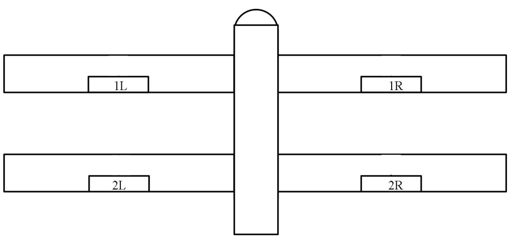

Figure 1. Aerodynamic layout diagram of UAV

The schematic diagram of the whole process of dive leveling of near space parachute UAV

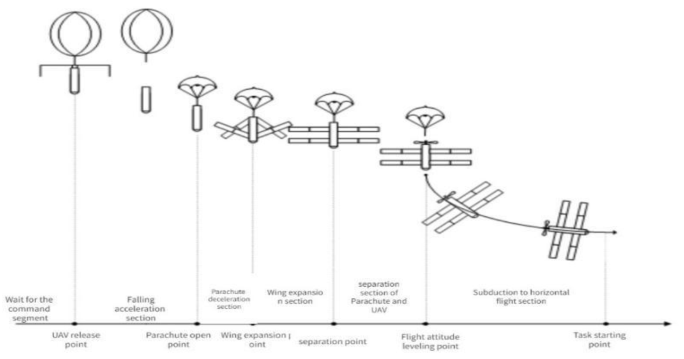

Figure 1. The schematic diagram of the whole process of dive leveling of near space parachute UAV

Research objectives

- Analysis of UAV performance characteristics
- Parachute hanging system modeling
- Modeling of UAV wing deployment process

Analysis of UAV performance characteristics

Analysis of lift-drag characteristics

The lift-drag characteristics of UAVs refer to the relationship between lift and drag generated by UAVs at different flight speeds and angles of attack.

Select a typical state point of the UAV, the lift-to-drag ratio curve of the UAV can be expressed as shown in Figure 3 and Figure 4 respectively:

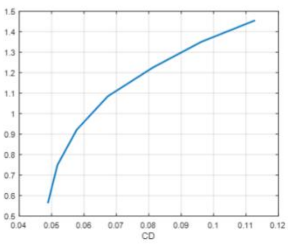

Figure 3. Lift-drag curve

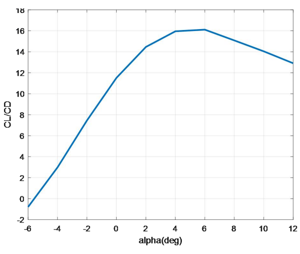

Figure 4. Lift-to-drag ratio curve

The lateral dynamic stability characteristics of the control object UAV studied in this paper are good. The distribution of the longitudinal and lateral characteristic roots of the control object UAV is shown in the following Figure 5 and 6:

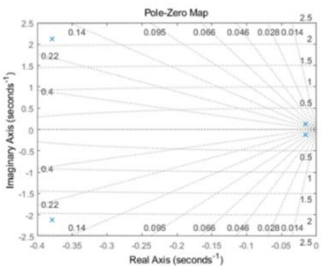

Figure 5. Longitudinal characteristic root distribution map

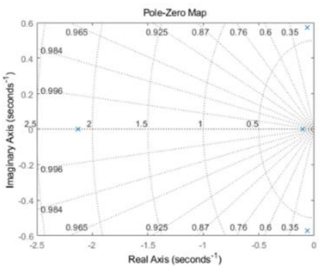

Figure 6. Lateral characteristic root distribution map

Parachute hanging system modeling

The following simplified assumptions are made when modeling the parachute:

(a) Suppose that the canopy of the parachute is opened and inflated quickly, and the direction of the binding force provided is along the direction of the umbrella rope pointing to the umbrella ;

b) Assume that the umbrella is axisymmetric and its shape is fixed ;

c) Assume that the pressure center position of the umbrella is the same as its geometric center position ;

d) Assume that the wake of the UAV has little effect on the canopy ;

e) The additional additional mass is used to reflect the additional influence caused by the unsteady motion of the parachute.

f) Assume that the umbrella rope and sling of the suspension system are elastic.

In the previous section, the establishment of the parachute dynamics model is completed. In this section, the analysis of the parachute suspension system model is carried out. The purpose is to calculate the constraint force and constraint torque between the body and the parachute during the parachute landing process of the UAV, and then the state variables of the UAV during the parachute landing process can be calculated [1]. In order to make the established hanging system model better reflect the state of the real system, this section will analyze the model based on the flexibility assumption, that is, the connecting parts in the system can be in a relaxed state[2]. The schematic diagram of the parachute hanging system is shown in Figure 8.

Based on the above assumptions, the definition of parachute body coordinate system diagram after parachute opening is as follows :

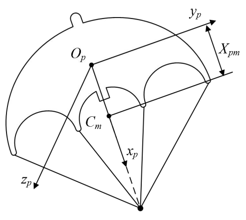

Figure 7. Parachute coordinate system diagram

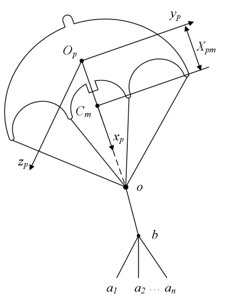

Figure.8. Parachute hanging system diagram

In order to facilitate the analysis, the sling umbrella rope ba is simplified as one. The modeling idea of equilibrium point is adopted, that is, within the simulation time step, the tension of the ba segment and the ob segment is guaranteed to be the same. That is :

$$T_{ob}+T_{ba}=0$$

$$T_{ob}=N_{ob}(E_{ob}\varepsilon_{ob}+B_{ob}\dot{\varepsilon}_{ob})\frac{r_o-r_b}{|r_o-r_b|}$$

$$T_{ba}=N_{ba}(E_{ba}\varepsilon_{ba}+B_{ba}\dot{\varepsilon}_{ba})\frac{r_a-r_b}{|r_a-r_b|} \tag{1}$$

N_{ob} and N_{ba} represents the number of umbrella ropes in ob and ba segments, both of which are 1 in this paper. E_{ob} and E_{ba} represents the elastic modulus of the two umbrella ropes, B_{ob} and B_{ba} represents the tension damping coefficient of the two umbrella ropes, ε_{ob} , ε_{ba} , $\bar{\varepsilon}_{ob}$, $\bar{\varepsilon}_{ba}$ represents the average strain and strain rate of the two umbrella ropes, and r_o , r_b , r_a represents the coordinates of the two umbrella ropes.

Modeling of UAV wing deployment process

The driving torque characteristics of the UAV wing deployment are related to the mechanical characteristics of the DC motor. In the case of idle speed n_0, the corresponding torque should be $T_N=0$. During the deployment of the wing, the wing will be subjected to air resistance and the friction group torque M_{fd} between the wing and the rotating mechanism, resulting in a speed $n_N < n_0$. Therefore, the motor should increase the wing drive distortion to overcome these resistances and torques. The corresponding driving torque is :

$$M_m = k_m(n_0 - \eta) - M_{fd} \quad (2)$$

$$\eta = d\Lambda / dt \quad (3)$$

In formulas (2) and (3), k_m is the derivative of the mechanical characteristic curve of the motor, and Λ represents the angle of the wing expansion. Based on the above analysis, the driving force and driving torque during wing deployment can be simplified as shown in Figure 9 below :

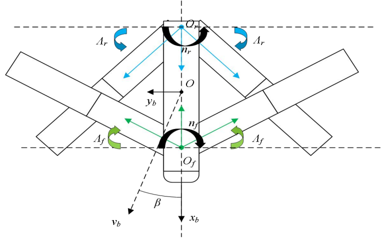

Figure 9. Simplified schematic diagram of driving torque during wing deployment process

The uncertainty impact in the expansion process can be described in the following form :

$$X_{pulse} = [0\ 0\ 0\ \phi_{pulse}\ \theta_{pulse}\ \psi_{pulse}\ p_{pulse}\ q_{pulse}\ r_{pulse}\ 0\ 0\ 0]^T \quad (4)$$

In the formula, the value with $pulse$ symbol in the parameter subscript is the amplitude of the corresponding pulse function, which is related to the parameters of the wing structure and can be obtained through relevant experimental analysis.

Summary

The control object and research process are defined in detail, and the modeling of important stages and processes is completed accordingly. Firstly, a six-degree-of-freedom nonlinear motion model of UAV is established based on aerodynamic data and flight dynamics, and related performance analysis is completed. Then, based on the parachute kinematics, the parachute-UAV suspension system is modeled. The simulation results show that the established process model meets the design requirements. Finally, the simplified modeling of the wing deployment process is completed. It lays a foundation for the research and design of UAV control strategy and control law.

References

[1] Li Guangchao, Ma Xiaoping. Analysis of Parachute Recovery Motion of Unmanned Aerial Vehicle [J]. Flight Mechanics, 2007,25 (4) : 25-28.
[2] Raghavan B, Patil M J. Flight control for flexible, high-aspect-ratio flying wings[J]. Journal of guidance, control, and dynamics, 2010, 33(1): 64-74.