Dumbbell : A High Efficiency Coaxial Unmanned Helicopter

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CONTENT

01 Introduction

Coaxial Helicopter
- ✓ Compact footprint
- ✓ Higher Flight Efficiency
- ✓ Superior hover stability
- ✓ High maneuverability

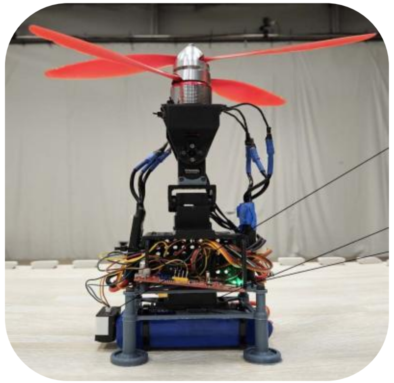
Ka-52

Swashplate
Mechanical complexity

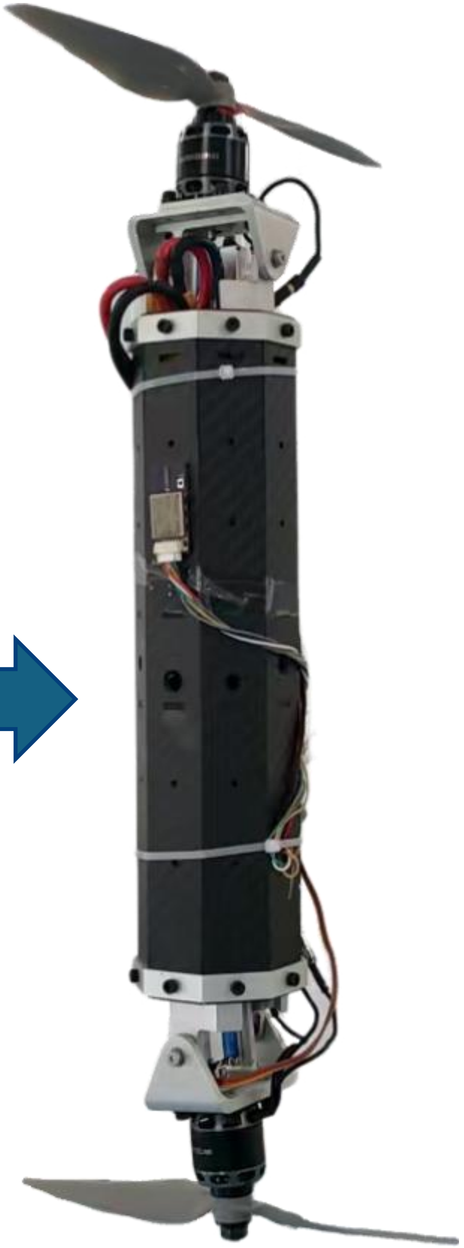
Normal Coaxial UAVs

Complex control

Aerodynamic coupling



Novel Coaxial UAVs

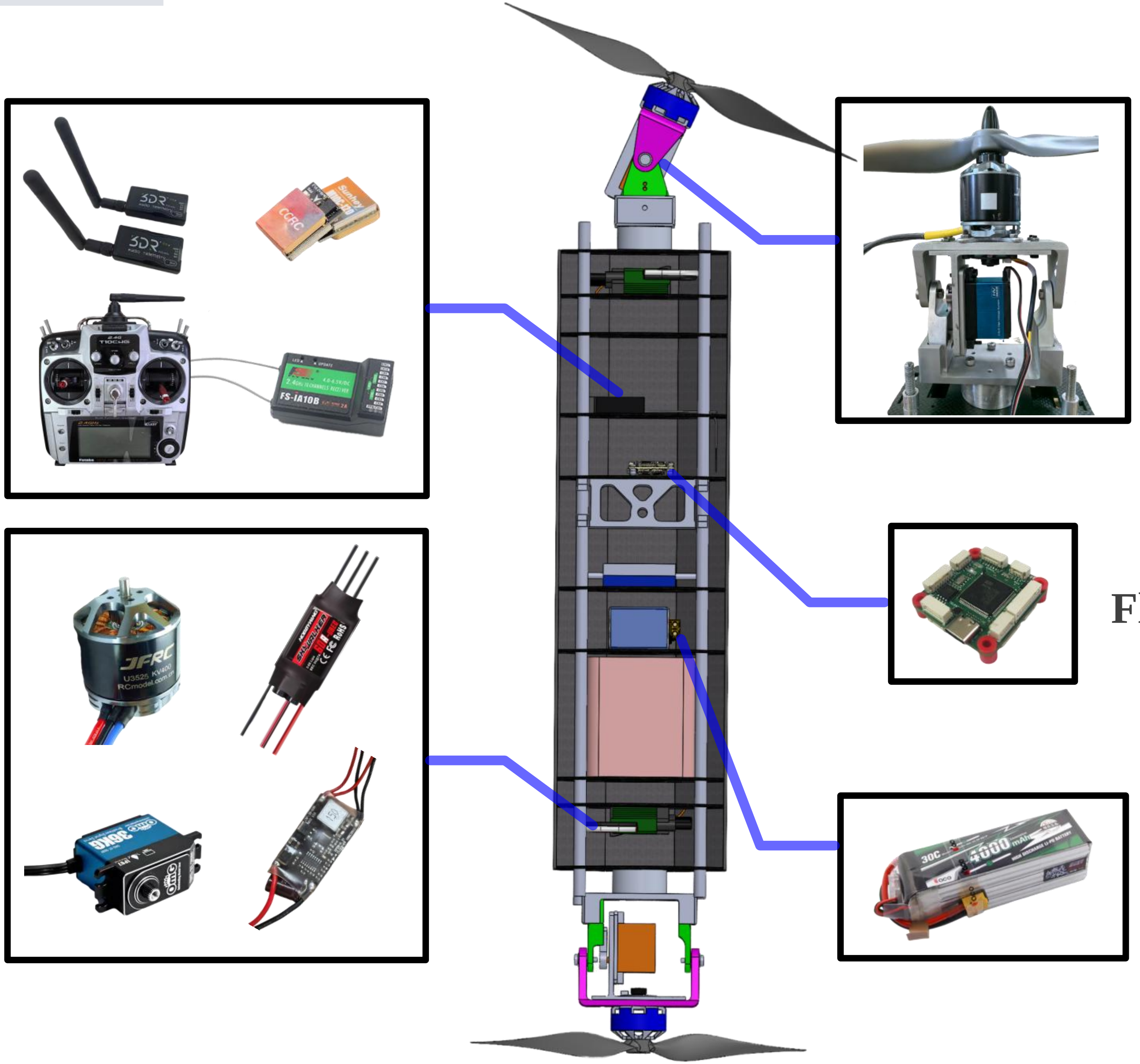


Dumbbell

02 System composition

Communication System and Sensors

Propulsion and Actuation System



Upper Rotor System

Flight Control Board

Battery

Modeling and Control

Modeling

Kinematic Model[1]:

$$\dot{p} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = R_p V_b \qquad R_p = \begin{bmatrix} C_\theta C_\psi & S_\phi S_\theta C_\psi - C_\phi S_\psi & C_\phi S_\theta C_\psi + S_\phi S_\psi \\ C_\theta S_\psi & S_\phi S_\theta S_\psi + C_\phi C_\psi & C_\phi S_\theta S_\psi - S_\phi C_\psi \\ -S_\theta & S_\phi C_\theta & C_\phi C_\theta \end{bmatrix}$$

$$\dot{a} = \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = R_a \omega_b \qquad R_a = \begin{bmatrix} 1 & S_\phi T_\theta & C_\phi T_\theta \\ 0 & C_\phi & -S_\phi \\ 0 & \frac{S_\phi}{C_\theta} & \frac{C_\phi}{C_\theta} \end{bmatrix}$$

Dynamic Model[2]:

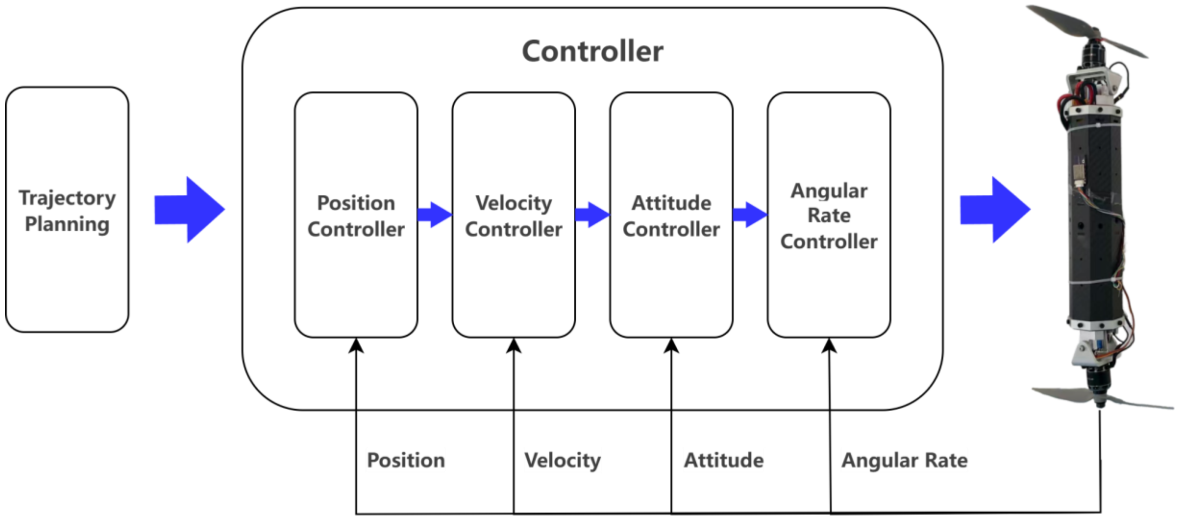
$$\dot{V}_b = \frac{F_b}{m} + \frac{F_g}{m}$$

$$\dot{\omega}_b = J^{-1} M_b$$

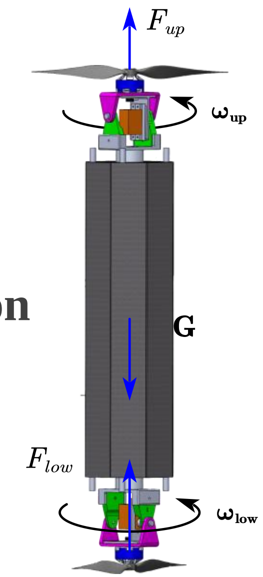
$$F_g = \begin{pmatrix} -mgS_\theta \\ mgS_\phi C_\theta \\ mgC_\phi C_\theta \end{pmatrix}$$

Note 1: The pitch angle θ remains within −90° to 90° during actual flight, avoiding gimbal lock; thus Euler angles are adopted for rotation representation.

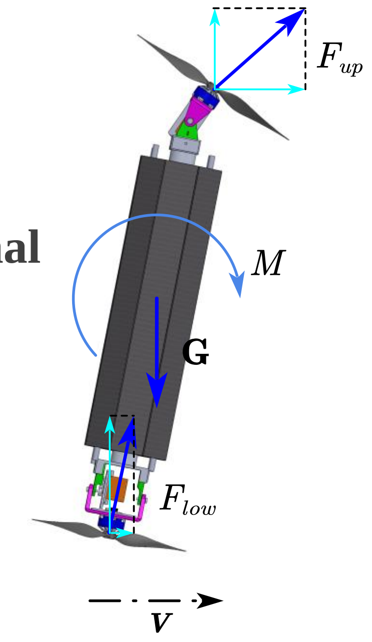
Note 2: Coriolis forces are neglected and the inertia matrix *J* is diagonal.



Yaw and Heave Motion

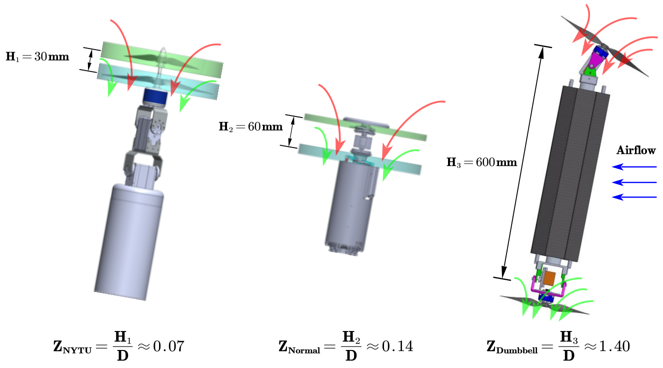


Longitudinal Motion

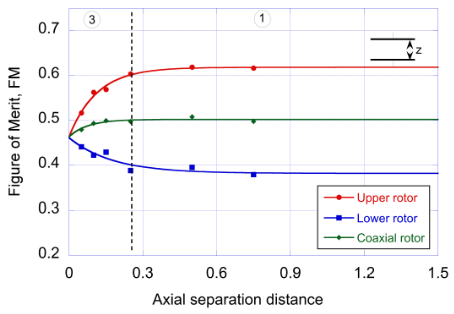


Flight Efficiency

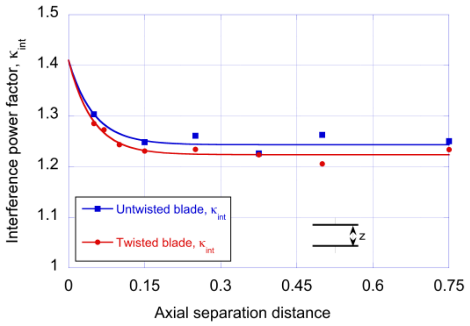
(a)



(b)



(c) [7]



(d) [7]

Note:

- Figure (a) presents aerodynamic simulations of the Dumbbell configuration performed using ANSYS Fluent.
- Figure (b) illustrates airflow direction and two rotors inter-spacing during forward flight for three coaxial configurations: NYTU Coaxial,
- Normal Coaxial, and Dumbbell.
- **A higher figure of merit (FM) value indicates superior aerodynamic efficiency of the rotor or coaxial rotor system.**
- **A higher interference loss factor (k_{int}) signifies heightened aerodynamic interference effects within the coaxial rotor system.**
- **As concluded in [7] and tabulated in Tables (c) and (b), the overall FM of the coaxial rotor system increases rapidly with growing axial spacing Z , then plateaus beyond Z = 0.15, while rotor-rotor interference progressively diminishes.**

Conclusion:

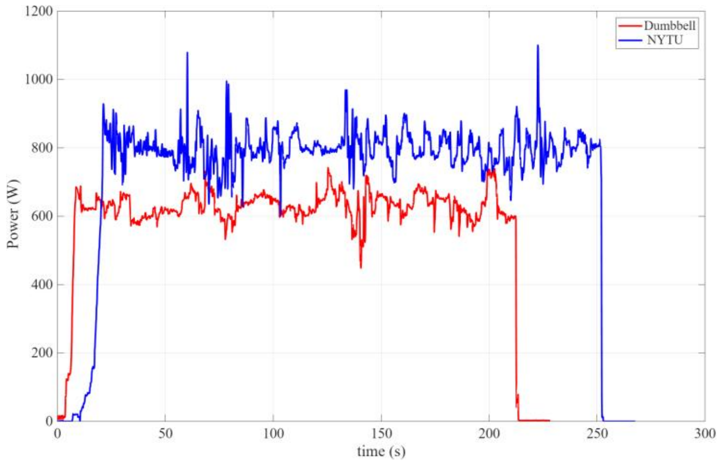
Attributed to its superior configuration, the Dumbbell achieves the highest flight efficiency among coaxial rotor architectures.

[7] Ramasamy M. Measurements comparing hover performance of single, coaxial, tandem, and tilt-rotor configurations. In AHS 69th Annual Forum, Phoenix, 2013: 31-32

05 Experimental Validation

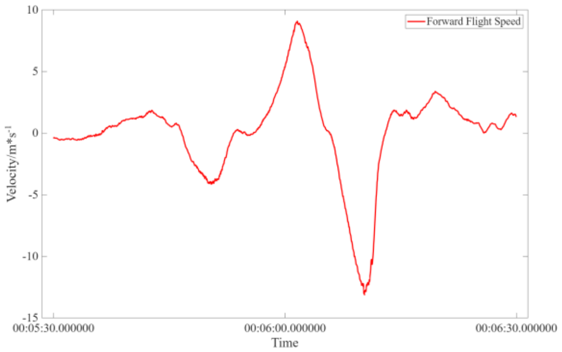
Dumbbell

NYTU Coaxial

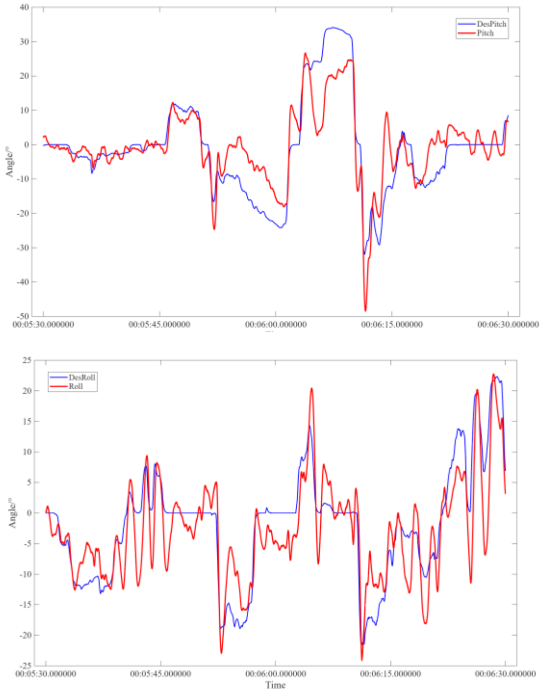


Comparison of Power

Flight Forward



Forward Flight Speed



Attitude Tracking

Conclusion

- ✓ **We proposed a novel coaxial rotor UAV configuration named "Dumbbell".**
- ✓ **We completed detailed mechanical design, lightweight manufacturing, and precision assembly for this UAV.**
- ✓ **We established its model and achieved stable control.**
- ✓ **We effectively solved the complex structure and aerodynamic coupling problems of traditional coaxial UAVs.**

Future Work: Establish a more accurate aerodynamic force model; Adopt more advanced control algorithms to enhance control performance; Optimize the mechanical structure by employing modular assembly.

07 Appendix

1. Specific Parameters of the Dumbbell

System Component	Parameter Specification
Motor	Sunnysky X2820 KV570
Propeller	APC 13*6.5
Electronic Speed Controller	Flycolor X-cross HV 60A
Servo	DSSERVO-RDS3235

Table.1

2. Testing and Calculation Method of the Thrust Compensation Coefficient *k*

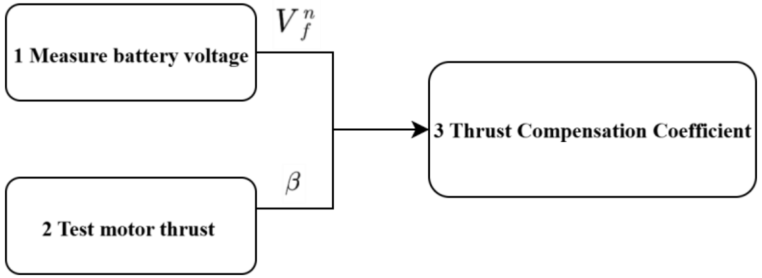


Figure.1 Test method for the thrust compensation coefficient

1 $$V_f^n = V_f^{n-1} + \alpha\left(\frac{V_r}{V_m} - V_f^{n-1}\right)$$

V_m -- Theoretical maximum voltage

V_r -- Resting voltage of the battery

2 As shown in Fig.2. On the fixed force test platform, the motor compensation coefficient β is derived by testing the rotor system's thrust output at different throttles to get the motor thrust curve, and comparing its nonlinearity with the theoretical thrust curve of the motor, ESC, and propeller under the same parameters.

3 $$k = \frac{1}{V_f^n\,(1-\beta) + \beta (V_f^n)^2}$$

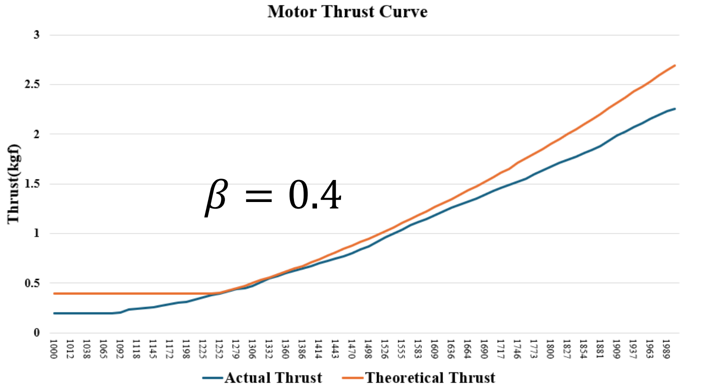


Figure.2 Test the motor compensation coefficient

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Thanks!