CASC: A Coaxial, Agile, and Servo-less tailsitter UAV with X-wing Configuration

Haotian Li*, Nan Chen*, Fanze Kong, Yuying Zou,
Shenji Zhou, and Fu Zhang

***Abstract*— This paper presents a novel uncrewed aerial vehicle (UAV) design named CASC. CASC uses a swashplateless mechanism to generate a moment for pitch and roll control without requiring additional actuators such as servo, reducing the number of components needed for control and enhancing reliability. Its reduced weight and number of actuators improve payload capacity and maneuverability. Meanwhile, CASC's coaxial propulsion system and the aerodynamic design improve power efficiency. Through the hovering test in the multi-rotor state, we preliminarily verified the design of the UAV.**

I. INTRODUCTION

Uncrewed aerial vehicles (UAVs) have undergone significant advancements in their design, encompassing a wide range of types and sizes. These advancements have drawn considerable attention in the domains of mechanical design and control algorithm development [1]. Among the various UAV types, the coaxial-rotor configuration has emerged as a promising design due to its distinctive structure that permits its adaptation to large, complex environments and flight missions.

As for coaxial UAVs, its design significantly impacts their flight performance and control logic. Conventionally, these UAVs are powered by a pair of coaxially arranged motors. The incorporation of a wing in such systems is a favourable option owing to the enhancement in efficiency and speed in the fix-wing flight mode it offers.

In this way, a novel design of coaxial UAV, named CASC, is developed to incorporate a swashplateless mechanism and X-wings to address the aforementioned issues introduced in this paper. The swashplateless mechanism is a passive structure that can generate lateral moments by controlling the high-frequency acceleration and deceleration of the motor without the need for additional actuators. The principle of the swashplateless mechanism has been utilized in the design of a coaxial configuration UAV detailed in [2]. The X-wing design(as shown in Figure. 2) significantly provides more flexible flight mode for the UAV, enhances aerodynamic efficiency, increases the flying speed, and integrates the landing gear with the fuselage to improve the aircraft's maneuverability. Two swashplateless mechanisms are installed on the two motors separately, thereby enhancing the control effect of the aircraft while providing a certain redundancy of actuators. This design offers more speed, improved propulsion efficiency, and greater payload capacity compared to existing tailsitter designs, thus making it a viable option for operation in large and complex environments.

TABLE I
SPECIFICATIONS OF CASC

Item	Parameter
Length	62.6 cm
Width	30.8 cm
Height	40.4 cm
Total weight (with battery)	1.4 kg
Thrust weight ratio	3.1

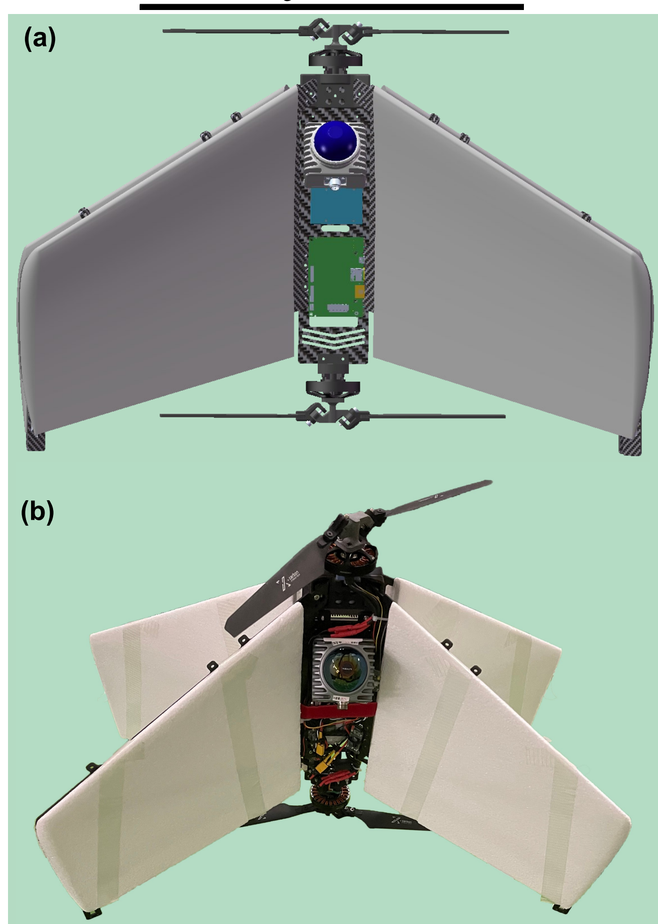

Fig. 1. Our coaxial and servo-less tailsitter UAV, named CASC.

II. SYSTEM DESIGN

A. UAV Structure and Avionics

We designed and manufactured a coaxial, servo-less tailsitter UAV called CASC, which could be used for effi-

*These two authors contribute equally to this work.
All authors are with the Department of Mechanical Engineering, The University of Hong Kong (HKU), Pokfulam, Hong Kong. {*haotianl,cnchen,kongfz,zyycici,shenjizhou*}*@connect.hku.hk*, {*fuzhang*} *@hku.hk*.

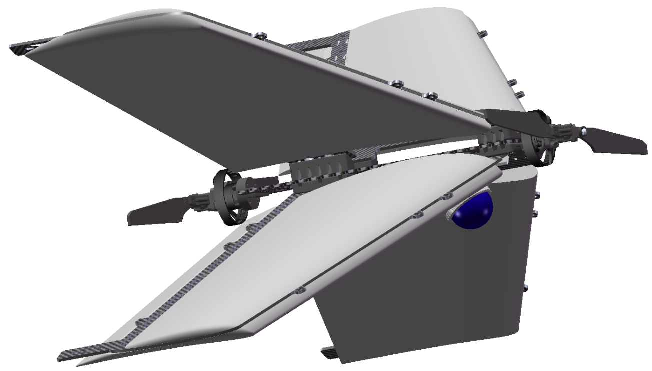

Fig. 2. Proposed UAV in fix-wing flight status.

cient exploration and simultaneous localization and mapping (SLAM) in large spaces [3]–[6].The composition of the aircraft can be seen from Figs. 1 and 3.

The avionics system of the UAV is centered on the Pixhawk 4 mini flight controller, which is securely mounted to the fuselage. Two brushless motors and two magnetic encoders are linked to the controller, governing all aircraft movements and precisely measuring the rotor angle. A swashplateless mechanism is employed to generate lift and moment through rotational motion of the motors. The resultant UAV design boasts a width of 30.8 cm and a weight of 1.4 kg, and further detailed parameters are shown in Table I.

B. X-wing design

The UAV featuring an X-wing structure exhibits superior control performance characteristics in the multi-rotor flight mode in comparison to those equipped with rudders with servos. This is attributed to the absence of ailerons that have huge inertia when moving, as well as there will be no decrease in control torque due to the decrease in surface flow velocity of the aileron during rapid descent [7]–[9]. Simultaneously, in fixed-wing flight conditions, the X-wing wing design can provide greater lift with a smaller projected area, enabling rapid flight in narrow and complex environments. Additionally, it effectively prevents aircraft sideslip during turns, enhancing flight robustness.

C. Swashplateless Actuator

The swashplateless mechanism with improved structure is illustrated in Fig. 3. The side hubs are connected to the central hub via two passive hinges in an asymmetrical manner. The rotation of these hinges, as a result of blade inertia, is induced by the periodic acceleration and deceleration of the motor, also known as motor speed modulation. This leads to variations in pitch angle changes of the positive and negative blades, with the blade exhibiting an increased pitch angle producing greater thrust while the blade displaying a decreased pitch angle generates less thrust, ultimately resulting in the generation of a net moment. The original design and the functioning principles of the mechanism are further elaborated upon in [10], [11]. Different from the original design, the improved design used in this UAV features the addition of ball bearings and pressure bearings, aimed at mitigating the friction generated by the high-frequency rotation of the hinges and providing a smoother output of moment with more rapid response when compared to the original design. The propulsion system is shown in Fig. 3.

III. Experiments

The experiment is to preliminary evaluate the design, performance, and robustness of CASC through a takeoff and hovering experimental test. We conducted flight tests of the CASC in the airfield using manual mode under attitude control. The CASC took off smoothly from the ground and hovered for approximately 30 seconds. During the experiment, the aircraft exhibited no abnormal vibrations, and the swashplateless mechanism demonstrated sufficient control performance. This lays a solid foundation for future experiments, including outdoor flight tests, disturbance rejection tests, and fix-wing flight tests.

IV. Conclusion

In this paper, we present a novel design for a coaxial servo-less tailsitter UAV equipped with an X-wing design that enhances both flight range and speed. By incorporating a swashplateless mechanism, the UAV's full attitude can be controlled without the need for traditional actuation methods which is typically based on servo-driven ailerons or swashplates. We validate the overall design of this coaxial tailsitter UAV by conducting a takeoff and hovering test. In summary, our proposed design is compatible, it promotes flight range, speed, and mechanical simplicity, while retaining a similar level of maneuverability and robustness.

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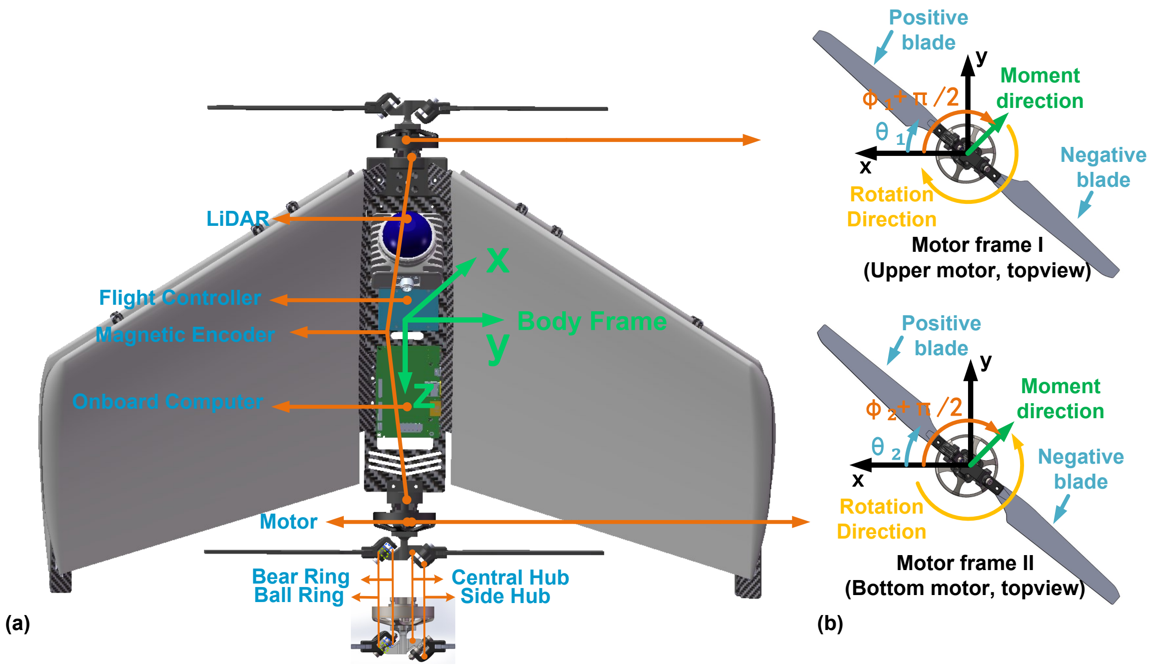

Fig. 3. Structure illustration. (a) The structure of CASC and the swashplateless actuator. (b) The definition of motor frames and angles.

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