

Original Paper

Optimal Design of a Small Multi-Purpose Fixed-Wing Flying Platform Based on Arduino Open-Source Hardware

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Abstract

To address the limitations of traditional small fixed-wing unmanned aerial vehicles (UAVs), such as their fixed configuration, high structural integration, and difficulty in rapid reconfiguration based on mission requirements, this paper designs and implements a small intelligent multi-purpose fixed-wing flying platform based on Arduino open-source hardware. Centered on a high degree of structural modularity, the platform utilizes 3D printing rapid manufacturing technology and standardized mechanical and electrical interfaces to divide the airframe into multiple functional modules, enabling free combination and rapid assembly of different configurations. In terms of structural design, key load-bearing components and module interfaces were optimized to reduce overall weight while ensuring structural strength and stiffness, supporting flexible configurations such as V-tail, T-tail, and various wingspans and payload types. Regarding system implementation, an Arduino Nano serves as the core control unit, integrated with inertial measurement, barometric altitude, data storage, and LoRa wireless communication modules, constructing an open, low-cost flight control and data acquisition system. Through aerodynamic simulation analysis, 3D printing manufacturing, and ground testing validation, the results demonstrate that the platform possesses good structural stability, assembly efficiency, and configuration scalability, providing a reference for teaching experiments and multi-purpose validation.

Keywords

arduino, fixed-wing UAV, open-source hardware, modular design, 3D printing

1. Introduction

With the widespread application of unmanned aerial vehicle (UAV) technology in fields such as surveying, reconnaissance, logistics, and scientific research, there is a growing demand for low-cost, highly adaptable, and rapidly deployable small-scale flight platforms. Traditional fixed-wing model

aircraft or commercial UAVs often adopt integrated or limited modular designs, making it difficult for users to perform deep and flexible hardware reconfiguration based on specific mission requirements. This limitation restricts their application in innovative research and multi-purpose validation.

The rapid development of open-source hardware and additive manufacturing has provided innovative solutions to the above challenges. 3D printing enables the rapid, low-cost, and customized fabrication of complex structures, while open-source flight controllers lower the development threshold for flight control systems. This makes the personalized design and manufacturing of fixed-wing flight platforms relatively easier. For instance, the micro-logistics UAV launched by Germany's Volocopter features a carbon fiber frame (Karpstein, Holzapfel, Biberthaler et al., 2024), with a total weight of only 1.2 kg and a cost controlled within \$3,000, making it suitable for campus delivery scenarios. In China, the field of small fixed-wing UAVs is gradually achieving a balance between low cost and high performance. For example, the UAV platform developed by Northwestern Polytechnical University (Wang, Li, & Zhou, 2011) employs lightweight carbon fiber materials and a modular design, with the overall cost kept under 10,000 RMB, making it a popular tool for scientific research experiments among university students.

In summary, most fixed-wing flight platforms are limited by the constraints of their fixed airframe configurations, making it difficult to adapt freely to varying mission requirements. This research focuses on the modularization and rapid manufacturing of the flight platform itself, aiming to construct a physically reconfigurable carrier. This paper primarily elaborates on the modular structural design of the flight platform, the 3D printing-based manufacturing process, the integration scheme for open-source hardware, and the ground validation process. This work lays a solid foundation for subsequent research on core control algorithms and mission payload optimization.

2. Overall Design

The design is centered on the core principles of modularity, open-source accessibility, and ease of use, aiming to develop a rapidly reconfigurable small fixed-wing flight platform based on Arduino open-source hardware. The standard configuration of this flight platform features a V-tail, high-wing, straight-wing design, twin engines, a tricycle landing gear, and wingtip devices to reduce induced drag. At a wingspan of 1.2 meters, the design enables flexible layout transformations and modular assembly by decomposing the aircraft into multiple standardized functional modules, facilitating on-demand modifications for various flight platform configurations.

3. Modular Structural Design

3.1 Module Division

The basic components include the nose cone, equipment bay, payload bay, fuselage aft section, central wing box, and tail boom. The wings are categorized into three types based on interface and function (flaperon type, pylon payload interface type, and conventional type), and are equipped with associated

control surfaces, winglets, V-tail stabilizers and control surfaces, engine nacelles, and landing gear bays.

3.2 Optimized Design of Components

3.2.1 Payload Bay

The payload bay serves as a critical structural component connecting the central wing box to the forward and aft sections of the fuselage. As one of the primary load-bearing structures, it is fabricated with a higher infill density during the 3D printing process to enhance its overall strength, stiffness, and fatigue resistance. A large access hatch is opened on the underside of the bay, which serves two purposes: on one hand, it allows for the accommodation of bulky or irregularly shaped experimental payloads, thereby improving the platform's versatility and mission adaptability; on the other hand, this opening facilitates the deployment of internal payloads, making it suitable for applications such as educational experiments and functional validation. The underside hatch is secured to the main body of the payload bay using a four-corner snap-fit connection, as illustrated in Figure 1. This design meets structural strength requirements while enabling quick assembly and disassembly, further enhancing the platform's expandability.

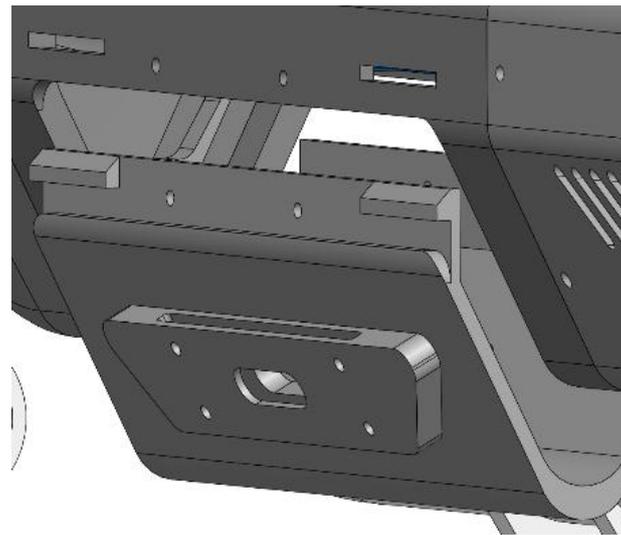


Figure 1. Payload Bay and Its Hatch Cover

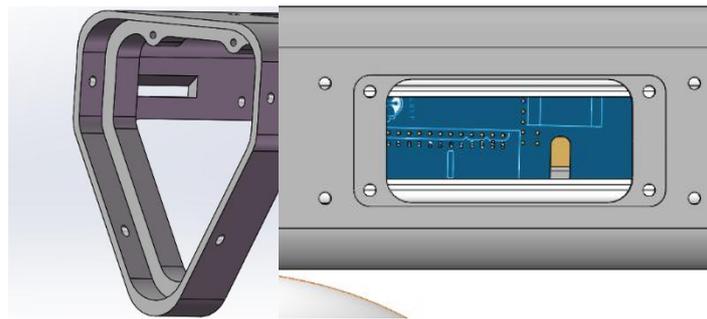
3.2.2 Fuselage Aft Section, Tail Boom, and Nose Cone

The fuselage aft section is designed to achieve a smooth transition from the mid-fuselage to the tail structure, with its cross-sectional form gradually converging from a pentagonal interface at the front to a circular interface at the rear. Through the incorporation of this section, the tail boom can be rapidly replaced while keeping the forward fuselage structure unchanged, thereby enabling the switching between different tail configurations such as the T-tail and V-tail.

The tail boom features three tail attachment interfaces structurally, with any two adjacent interfaces positioned at an angle of 120° to each other. By utilizing different combinations of these interfaces, various tail configurations, including the T-tail and V-tail, can be quickly installed and switched,

catering to diverse flight missions and experimental requirements. Both the front and rear ends of the tail boom adopt circular F-type interfaces. Additionally, servo mounting slots are integrated into the tail boom to provide fixed positions for the rudder and elevator servos, resulting in a more rational control system layout and facilitating subsequent maintenance and replacement.

The rear of the nose cone is equipped with a pentagonal interface, as shown in Figure 2(a), to connect with the equipment bay. The structure gradually converges toward the forward direction of the aircraft, with an overall design pursuing a smooth and continuous streamlined shape to enhance aerodynamic performance. While meeting the requirements of the external shape design, the internal structure of the nose cone is used to secure the main carbon fiber tube spar of the fuselage, ensuring that the forward structure possesses sufficient structural strength and assembly stability while maintaining an aesthetically pleasing appearance. A camera lens slot is reserved at the front of the nose cone.



(a) Pentagonal interface; (b) Top square interface

Figure 2. Interfaces between Main Cabin Sections

3.2.3 Central Wing Box

The central wing box primarily serves to concentrate and transmit the lift loads from the wings to the fuselage, and it is also the core component of the overall structural layout. To ensure sufficient structural strength and stiffness under flight loads, a higher infill density is also adopted during the 3D printing manufacturing process. The wing interfaces at both ends of the wing box are correspondingly designed, with a G1 continuous smooth connection form adopted in the structural transition areas. This allows the wing spars to run straight through from the center of the fuselage, thereby reducing stress concentration caused by abrupt structural changes. An antenna slot is provided on the top of the central wing box to guide the receiver antenna from inside the fuselage to the exterior. This minimizes signal blockage caused by the carbon fiber structure and electronic devices, improving communication stability and the reliability of the flight control system (Xie, 2023; Li, 2022).

3.2.4 Equipment Bay

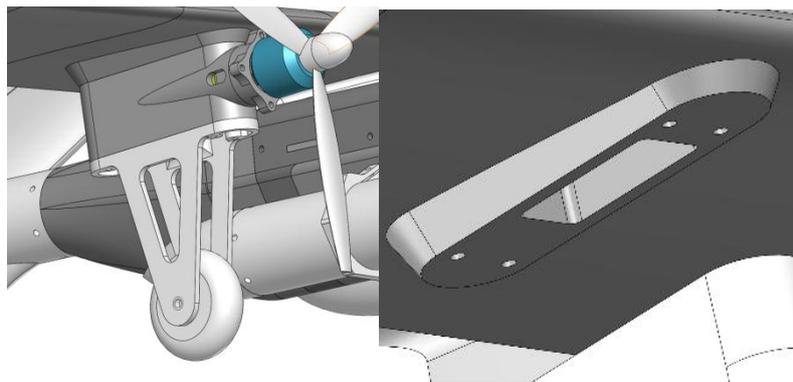
The equipment bay is primarily used to house the flight control system, battery, electronic speed controllers (ESCs), and related electronic equipment. Strip-shaped ventilation slots are opened on both sides to improve air circulation inside the bay, reducing heat accumulation generated during the operation of electronic devices. This mitigates the impact of temperature variations on the material

properties and geometric stability of the 3D-printed airframe. A square interface, as shown in Figure 2(b), is designed on the top of the equipment bay for docking and fixing with the central wing box according to specific configuration requirements. In cases where connection with the central wing box is not needed, this opening also serves as an inspection port for easy viewing of the bay's interior. It can be covered with a lid to ensure surface smoothness.

3.2.5 Engine Nacelle and Landing Gear Bay

The interface type of the engine nacelle is consistent with the pylon payload interface shown in Figure 3(b), allowing it to be mounted under the wing in a podded configuration based on mission requirements. This design provides high flexibility in the arrangement of the propulsion system, facilitating the replacement of power components of different specifications or the conduct of comparative experiments with multiple schemes.

The interface type of the landing gear bay is also consistent with the pylon payload interface shown in Figure 3(b) to enhance structural commonality and component interchangeability. The optionally installed nose landing gear bay is connected via fixing holes at the lower front part of the equipment bay. An H-shaped structure is used internally to constrain the nose landing gear, effectively improving its stability and resistance to lateral deformation during taxiing, takeoff, and landing.



(a) Assembly diagram; (b) Pylon payload interface

Figure 3. Landing Gear and Engine Nacelle Components

3.2.6 Main Wings and Tail Wings

The flaperon-type main wing section is structurally designed with mounting slots and fixing holes for the control surfaces. Additionally, a separate servo slot is provided on the underside of the wing to embed the servo within the wing structure, thereby minimizing the impact of exposed components on aerodynamic performance. A square space is reserved at the pylon payload interface shown in Figure 3(b) to ensure the continuous routing of electrical wiring between the wing and the fuselage. Countersunk threaded holes are provided at the top of the interface, allowing long bolts to pass through and securely fasten the pylon to the underlying structure.

The conventional configuration main wing retains only a smooth and continuous wing surface,

adopting the classic NACA4412 airfoil (Petinrin & Onoja, 2017) to meet conventional flight performance requirements. The tail wings are left-right symmetric and utilize the NACA0012 airfoil to ensure aerodynamic consistency and structural uniformity of the empennage.

3.2.7 Sidewall Payload Pylon

The sidewall payload pylon is connected to the protruding clips on both sides of the payload bay's underside hatch cover via a snap-fit structure (as shown in Figure 4). This is intended to expand the forms of payload installation and enhance the platform's adaptability in multi-purpose applications. When employing this connection method, additional bolts are required to fasten the payload bay body and the underside hatch cover together. This further reinforces the overall structural strength, ensuring the safety and reliability of the connection points under flight loads and vibrational stresses.

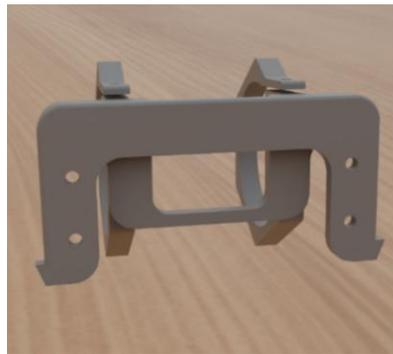


Figure 4. Sidewall Payload Pylon

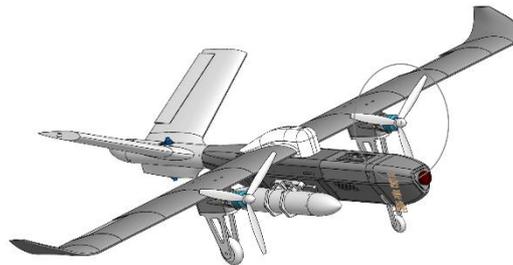


Figure 5. View of the Standard Configuration

3.3 Standardized Interfaces

The connection between modules primarily utilizes a mechanical interface combining bolt-and-nut structures with locking pins, ensuring precise positioning, secure connections, and interchangeability of fasteners. For electrical wiring connections, pin headers and female headers are mainly employed, which facilitate the free plugging and unplugging of expansion modules while reducing the rate of poor contact, significantly simplifying the assembly process. **This** flexible assembly mode allows additional modular components to be connected as needed to assemble special airframe configurations, such as

twin-fuselage (An, Xie, Meng et al., 2021) or T-tail variants.

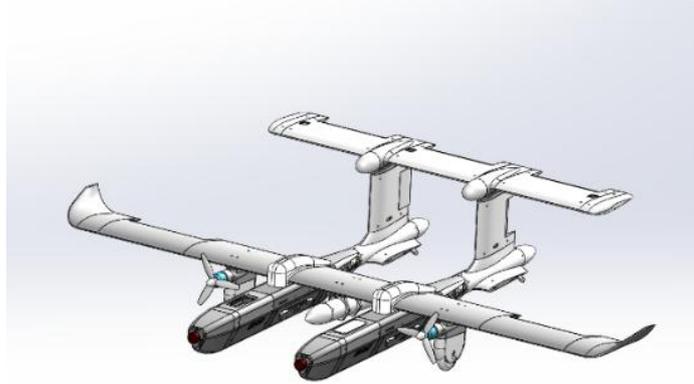


Figure 6. T-Tail, Twin-fuselage Configuration (under-wing Mounting of Bulky Payloads)

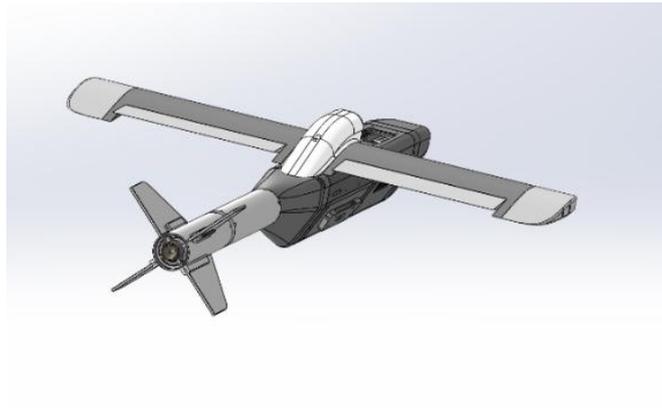


Figure 7. Configuration Powered by a Solid Rocket Motor

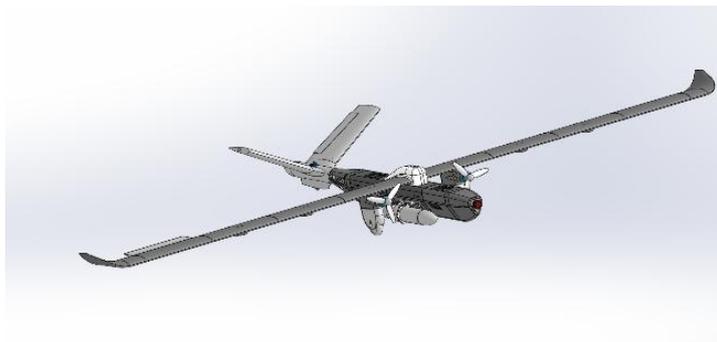


Figure 8. Configuration with Additional Wing Structural Components to Increase Wing Aspect Ratio, Suitable for Low-speed Gliding

3.4 3D Printing Materials

Apart from a few load-bearing components such as the main wing spar and servo linkages, approximately 80% of the structural parts (including the fuselage shell, wing ribs, control surfaces, and

connectors) are fabricated using foaming PLA (Polylactic Acid) material via fused deposition modeling (FDM) technology. This material undergoes a foaming process during printing, which reduces the overall material density, significantly lowering component weight while maintaining comparable volume. As a result, the unmanned structural weight of the platform is controlled at 542 grams. With the installation of the complete electronic control system and battery, the total weight reaches 931 grams, offering favorable thrust-to-weight ratio potential.

4. Control System Design

4.1 Core Flight Control Unit

The core flight control unit employs an Arduino Nano development board equipped with an Atmega328p chip. It is a simple, flexible, and user-friendly open-source electronic platform. Featuring 11 digital pins and 7 analog pins, it offers advantages in development convenience and compact size, facilitating integration within the tight fuselage space. It is responsible for receiving remote control signals, processing sensor data, and outputting control commands .

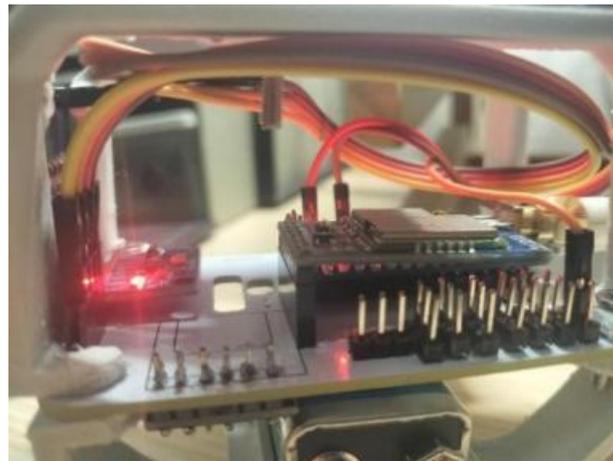


Figure 9. Electronic Control Main Board

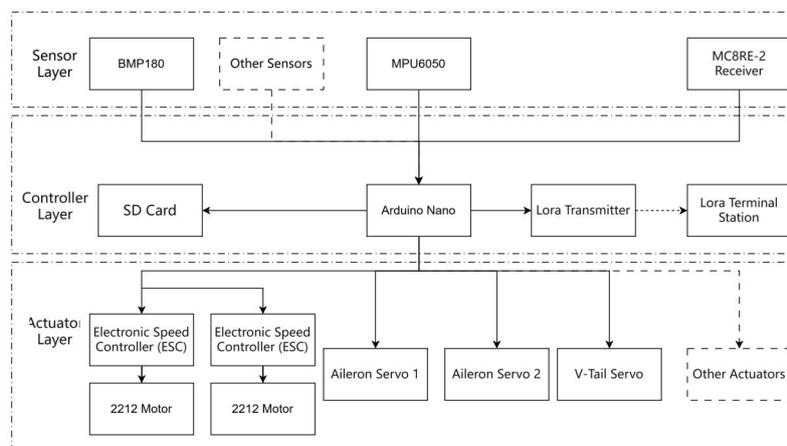


Figure 10. Module Connection Diagram

4.2 Sensors and Data System

The MPU6050 inertial reference module integrates a gyroscope and accelerometer, providing three-axis angular velocity and acceleration data for the aircraft. This facilitates attitude calculation for flight test analysis. The BMP180 barometer is used to estimate relative altitude. A Micro SD card module is employed for locally storing flight logs and sensor data. The LoRa module enables remote wireless transmission of critical data (such as attitude, position, status, and mission payload monitoring) over a range of several kilometers back to the ground station for monitoring purposes.

4.3 Actuators and Expansion Interfaces

The flight control board outputs PWM signals to electronic speed controllers (ESCs) to regulate motor speeds and drives multiple servos to control the ailerons, elevator, and rudder. The main flight control board reserves several sets of standardized analog input/output interfaces, facilitating user integration of additional sensors, actuators (servos), or mission payloads.

4.4 Power System, Receiver, and Power Supply

The standard configuration adopts a twin-engine, under-wing mounted layout. The receiver used is the MC8RE-2 paired with its corresponding transmitter, supporting eight-channel control. Two KV1000 2212 motors are employed, paired with three-blade symmetrical 8-inch propellers. The ESCs used are Hobbywing ESCs, and the power system is powered by a 2200mAh lithium battery. The theoretical thrust of the twin engines is approximately 1.2kg, resulting in a thrust-to-weight ratio of about 1.289 for the empty takeoff weight.

4.5 Code Design

The code implements standard six-channel (throttle, elevator, aileron, rudder, mode switch, auxiliary) remote control signal decoding and mixing processing. The main loop encompasses core tasks such as sensor data reading, attitude fusion algorithms based on quaternion calculation and Kalman filtering, and PWM signal output. Overall communication between components and data processing functions are achieved by invoking the following encapsulated libraries:

```
#include <Wire.h>
#include <MPU6050.h>
#include <Adafruit_BMP085_U.h>
#include <math.h>
#include <Servo.h>
#include <SD.h>
#include <SPI.h>
```

4.6 Data Processing

For the altitude data collected by the BMP180, an average of 10 consecutive readings is calculated to reduce anomalies caused by randomness. For the acceleration and angular velocity data from the MPU6050, the `dmpGetQuaternion()` method is used to compute the quaternion; the `dmpGetGravity()` method is used to obtain the gravity vector. Subsequently, the

`dmpGetYawPitchRoll()` method is employed to calculate the offset angles (pitch, roll, and yaw) on the three axes. Data such as these three-axis offset angles are transmitted back to the ground station host computer via the LoRa module for attitude simulation.

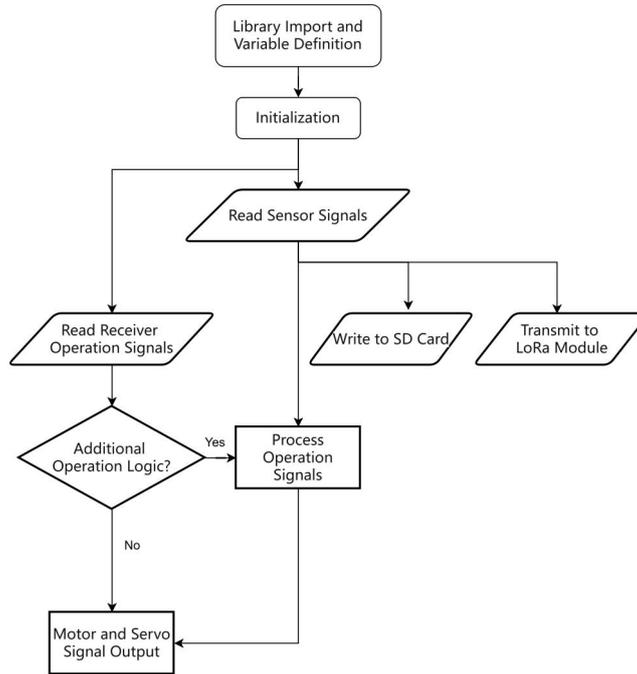


Figure 11. Arduino Nano Workflow Diagram

5. Manufacturing and Testing

5.1 Aerodynamic Simulation Validation

Prior to actual manufacturing, XFLR5 software was utilized to conduct aerodynamic characteristic analysis and static stability simulations for the standard high-wing V-tail configuration. As shown in Table 1, when the flight speed is 12 m/s and the angle of attack reaches 5°, the maximum lift-to-drag ratio is 14.833. Within the angle of attack range of -1° to 3°, the static stability margin and controllability reach an optimal cruising attitude. This validates the aerodynamic rationality of the modular structural design. The main wing adopts the NACA4412 airfoil, while the auxiliary surfaces utilize the NACA0010 airfoil. The results demonstrate a favorable static stability margin, excellent aerodynamic efficiency, and desirable stall and handling characteristics. These features permit slow flight, allowing non-professional operators sufficient reaction time for control.

Table 1. Aerodynamic Performance of the High-wing V-tail Configuration (airspeed 12 m/s)

Angle of Attack (Alpha)	Lift-to-Drag Ratio (CL/CD)	Static Stability Margin (%MAC)	Pitching Moment (Cm)
-2	3.246	-72.65	0.085
-1	6.160	-14.53	0.035

0	8.980	7.69	-0.016
1	11.159	18.8	-0.067
2	12.897	25.64	-0.119
3	13.936	30.77	-0.171
4	14.559	34.19	-0.224
5	14.833	36.75	-0.277
6	14.790	39.32	-0.331

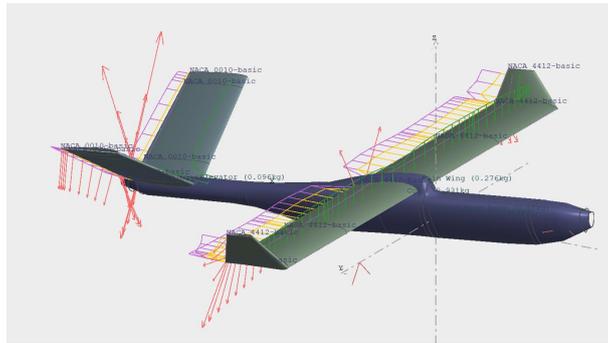


Figure 12. Aerodynamic Characteristic Analysis and Static Stability Simulation

5.2 Manufacturing of the Flight Platform Prototype

All structural components were fabricated using 3D printing technology, followed by systematic assembly. The assembly process adhered to the principle of modularity, with each functional module quickly connected via standardized interfaces and secured using common fasteners such as bolts.



Figure 13. Physical Prototype of the Fixed-wing Flight Platform in Standard Configuration

6. Conclusion

This paper presents the optimized design, simulation testing, and manufacturing of a highly modular and reconfigurable small-scale flight platform based on Arduino open-source hardware. It offers a novel design approach for rapidly modifying fixed-wing unmanned aerial vehicle (UAV) products from a single baseline model to adapt to diverse mission requirements. Furthermore, leveraging the flexible expandability of Arduino open-source hardware, the functional modification possibilities for

fixed-wing UAV platforms are significantly broadened.

Acknowledgments

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References

- An, C., Xie, C. C., Meng, Y. et al. (2021). Study on Flight Dynamics Stability and Augmentation Control of Multi-body Combined UAVs. *Engineering Mechanics*, 38(11), 248-256.
- Karpstein, R., Holzapfel, F., Biberthaler, P. et al. (2024). Potential of Advanced Air Mobility in German and Austrian Organ Transplantation. In: AIAA AVIATION FORUM AND ASCEND 2024. *Las Vegas, NV*, 3556.
- Li, Z. H. (2022). *Design and Flight Control of Hand-launched Fixed-wing UAV* (Master's Thesis). Central South University, Changsha. DOI: 10.27661/d.cnki.gzhnu.2022.003375.
- Petinrin, M. O., & Onoja, V. A. Computational Study of Aerodynamic Flow over NACA 4412 Airfoil. *British Journal of Applied Science & Technology*, 21(3), 1-11.
- Wang, H. J., Li, J., & Zhou, Z. (2011). Aerodynamic Design of Flying Wing Special Configuration UAVs. *Journal of Northwestern Polytechnical University*, 29(5), 789-793.
- Xie, M. H. (2023). *Key Structure Design and Optimization Method of a Certain Modular UAV* (Master's Thesis). Nanchang Hangkong University, Nanchang. DOI: 10.27233/d.cnki.gnchc.2023.000131.