Design and Demonstration of Fixed-Wing RC Plane

***Abstract*—This project presents the design and development of a fixed-wing radio-controlled (RC) aircraft with a maximum takeoff weight of 3 kilograms. The objective was to create an aerodynamically efficient and structurally robust model capable of stable flight performance within the specified weight constraint. The aircraft is specifically designed to operate at low cruise speeds in the range of 5 to 10 m/s, suitable for stable surveillance and sensor-based missions. The design process involved detailed aerodynamic analysis, including airfoil selection, lift and drag estimation, and stability considerations, to ensure optima‘l flight characteristics. Simultaneously, structural analysis was conducted to develop a lightweight yet durable airframe, using appropriate material selection and load-bearing calculations. The integration of these multidisciplinary approaches resulted in a balanced design that demonstrates practical application of theoretical principles in aerodynamics and structural engineering.**

***Index Terms*—RC aircraft, aerodynamic design, structural analysis, XFLR5, thrust estimation, airfoil, Cessna 172R**

I. Introduction

The design and performance of fixed-wing RC aircraft offer a practical platform to apply the fundamentals of aerodynamics and structural mechanics. In this project, we designed a fixed-wing RC plane with a maximum takeoff weight of 3 kg, inspired by the planform of the Cessna Skyhawk 172R — a widely used trainer aircraft known for its stability and balanced flight characteristics. The aerodynamic profile of the wing was analyzed using XFLR5, from which detailed lift and drag characteristics were obtained. Based on this data, the required thrust for steady flight was calculated, forming the foundation for propulsion and structural design decisions. A comprehensive study was carried out, focusing on wing shape, airfoil performance, and overall aerodynamic efficiency, supported by structural analysis to ensure the airframe could withstand the flight loads while maintaining minimal weight. The aircraft is controlled using roll, pitch, and yaw commands, which govern its ability to perform coordinated maneuvers and maintain stability during flight.

II. Design Requirements and Constraints

The RC plane was designed to meet the following requirements:

- Maximum takeoff weight: 3 kg
- Good longitudinal and lateral stability
- Ease of manufacturability using accessible materials
- Capability to carry onboard components such as motor, battery, and control electronics
- Designed with provisions to carry future payloads such as weather monitoring sensors, temperature monitoring devices, or a lightweight gimbal system.
- Optimized for low cruise speeds in the range of 5 to 10 m/s to support stable flight during surveillance or sensor-based payload operations.

III. Aerodynamic Design

A. Airfoil and Planform

The wing planform was inspired by the Cessna 172R trainer aircraft. Airfoil named NACA 2412 was selected, as it offers a good balance of lift and stall characteristics at typical approach speeds.

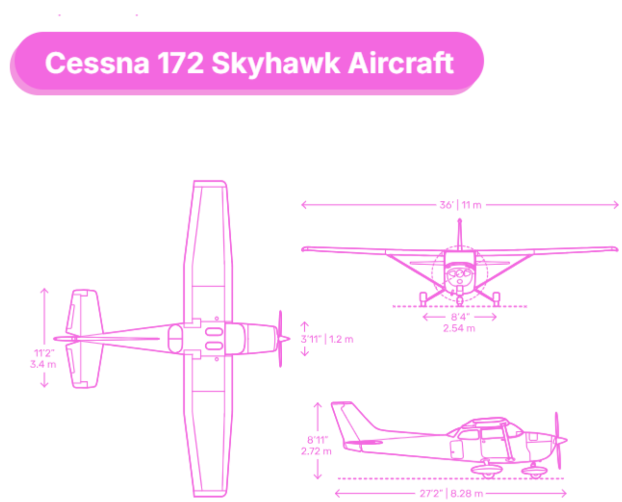


Fig. 1. Planform Views of Cessna Skyhawk 172R

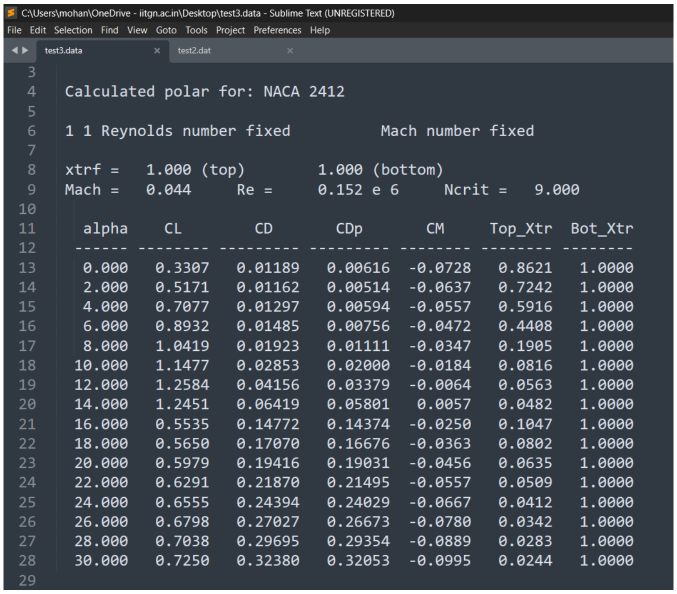
Cessna 172R-Inspired Planform Used in Design

B. XFLR5 Analysis

Using XFLR5, the lift and drag characteristics of the chosen wing geometry were simulated across a range of angles of attack. The airfoil selected for analysis was NACA 2412, and aerodynamic performance data such as lift coefficient (CL), drag coefficient (CD), and moment coefficient (CM) were obtained for use in further performance estimations.

For these simulations, the Reynolds number was calculated based on the maximum cruise speed and chord length. Assuming a freestream velocity of 10 m/s(max cruise speed), air density of 1.225kg/m^3, dynamic viscosity of 1.81×10^{-5}Pa·s, and a chord length of 25cm, the Reynolds number was computed as:

$$Re = \frac{\rho U_\infty c}{\mu} = \frac{1.225 \times 9 \times 0.25}{1.81 \times 10^{-5}} \approx 152{,}000$$



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Calculated polar for: NACA 2412

1 1 Reynolds number fixed          Mach number fixed

xtrf =   1.000 (top)        1.000 (bottom)
Mach =   0.044     Re =     0.152 e 6     Ncrit =   9.000

  alpha    CL        CD       CDp       CM     Top_Xtr  Bot_Xtr
 ------ -------- --------- --------- -------- -------- --------
  0.000   0.3307   0.01189   0.00616  -0.0728   0.8621   1.0000
  2.000   0.5171   0.01162   0.00514  -0.0637   0.7242   1.0000
  4.000   0.7077   0.01297   0.00594  -0.0557   0.5916   1.0000
  6.000   0.8932   0.01485   0.00756  -0.0472   0.4408   1.0000
  8.000   1.0419   0.01923   0.01111  -0.0347   0.1905   1.0000
 10.000   1.1477   0.02853   0.02000  -0.0184   0.0816   1.0000
 12.000   1.2584   0.04156   0.03379  -0.0064   0.0563   1.0000
 14.000   1.2451   0.06419   0.05801   0.0057   0.0482   1.0000
 16.000   0.5535   0.14772   0.14374  -0.0250   0.1047   1.0000
 18.000   0.5650   0.17070   0.16676  -0.0363   0.0802   1.0000
 20.000   0.5979   0.19416   0.19031  -0.0456   0.0635   1.0000
 22.000   0.6291   0.21870   0.21495  -0.0557   0.0509   1.0000
 24.000   0.6555   0.24394   0.24029  -0.0667   0.0412   1.0000
 26.000   0.6798   0.27027   0.26673  -0.0780   0.0342   1.0000
 28.000   0.7038   0.29695   0.29354  -0.0889   0.0283   1.0000
 30.000   0.7250   0.32380   0.32053  -0.0995   0.0244   1.0000
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Fig. 3. Lift, drag, and moment coefficients of NACA 2412 airfoil obtained from XFLR5 at Re 1.52×10^5, $N_{crit} = 9$

This value was used as the reference Reynolds number in XFLR5 to simulate aerodynamic behavior at typical flight conditions.

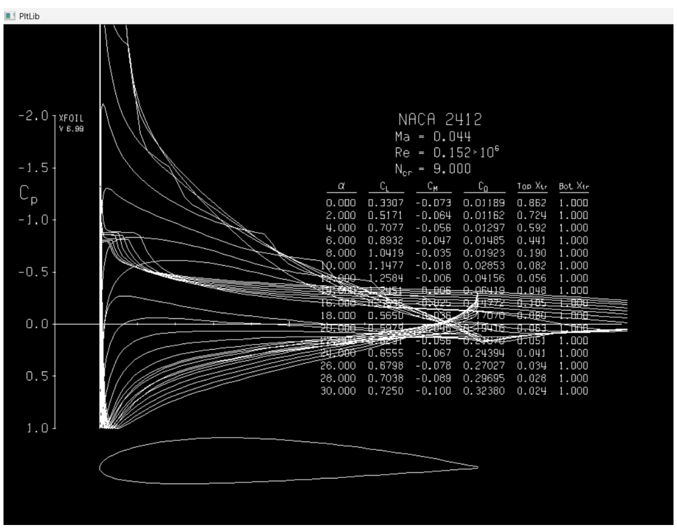

Fig. 2. Lift–Drag Polar of NACA 2412 (0° to 30° AoA) at Re 152,000

C. Thrust Calculation

From the obtained drag values through XFLR5, the required thrust for steady-level flight was estimated, assuming equilibrium between thrust and drag at cruise conditions. This estimation guided the sizing of the propulsion system, including motor and propeller selection.

A target thrust-to-weight (T/W) ratio in the range of 0.8 to 1.2 was considered to ensure sufficient acceleration, climb capability, and margin to overcome increased drag during maneuvers. Based on this, an appropriate motor-propeller combination was selected to deliver the necessary thrust while maintaining efficiency and compatibility with the aircraft's power and structural constraints.

D. Stability and Control

The aircraft's center of gravity (CG) and center of pressure (CP) were positioned to ensure both static and dynamic stability throughout flight. The CG was intentionally placed at approximately 12% of the wing's mean aerodynamic chord (MAC), ensuring a forward position relative to the neutral point to maintain positive static margin. This placement supports stable pitch behavior and safe handling characteristics.

Tail sizing and control surface effectiveness were also examined to ensure adequate authority in all three axes, particularly at low cruise speeds. The horizontal stabilizer was sized to provide sufficient nose-down moment, while the vertical stabilizer and rudder were designed to maintain yaw stability and control during turns and crosswind conditions.

E. Wing Sizing and Airfoil Selection

To ensure sufficient lift during cruise at 10 m/s, the wing sizing was based on the standard lift equation:

$$L = W = \frac{1}{2}\rho V^2 S C_L \tag{1}$$

Where:

- $W = 29.43$ N (corresponding to 3 kg mass)
- $\rho = 1.225$ kg/m^3 (air density at sea level)
- $V = 10$ m/s (cruise velocity)
- $C_L = 0.8$ (assumed lift coefficient for NACA 2412)

Solving for the required wing area:

$$S = \frac{2W}{\rho V^2 C_L} = \frac{2 \times 29.43}{1.225 \times 10^2 \times 0.8} \approx 0.60 \text{ m}^2 \tag{2}$$

This value suggested an ideal wingspan of:

$$b = \sqrt{AR \times S} = \sqrt{6 \times 0.60} \approx 1.90 \text{ m} \tag{3}$$

However, to enhance feasibility, simplify construction, and improve stability, the wingspan was limited to 1.5 meters. As a result, the mean aerodynamic chord (MAC) was adjusted to 0.25 m, resulting in:

$$S = b \times \text{MAC} = 1.5 \times 0.25 = 0.375 \text{ m}^2 \tag{4}$$

$$AR = \frac{b^2}{S} = \frac{1.5^2}{0.375} = 6 \tag{5}$$

This reduction in wing area means the aircraft produces less lift at 10 m/s, so additional thrust was incorporated to maintain level flight performance.

Airfoil Selection: The **NACA 2412** airfoil was chosen for its favorable low-speed lift characteristics and smooth stall behavior. The airfoil was analyzed using XFLR5 to extract lift and drag polar curves, supporting aerodynamic performance predictions under the revised geometry.

IV. Structural Design

A. Material Selection

Lightweight materials such as balsa wood and softwood were selected based on their favorable strength-to-weight ratios, ease of machining, and suitability for low-speed flight applications.

Balsa wood was used as the primary skin material to wrap the wing due to its extremely low density and good rigidity. Softwood strips were used as internal spars and supports to maintain the airfoil profile, as they offer sufficient stiffness while remaining lightweight. The airfoil sections were precisely cut using a laser cutting machine to ensure dimensional accuracy and consistency across the span.

Fig. 4. Wing Section

B. Load Analysis

Although detailed prior structural calculations were not performed, the airframe was assessed through practical testing by applying loads on the wing after manufacturing. This approach helped verify its ability to withstand typical flight loads. Spars and reinforcements were sized based on empirical judgment and adjusted as needed during assembly.

C. Fuselage and Wing Construction

The fuselage structure was kept simple to allow for easy assembly and convenient access to internal components such as the battery, ESC, and receiver. It was designed to minimize interference with the front-mounted propeller's airflow by maintaining a narrow profile near the nose. The fuselage cross-section was intentionally kept smaller at the front and gradually bulged near the wing root to accommodate structural reinforcements and ensure a smooth transition to the wing. The wing itself employed a single main spar to provide adequate rigidity and resist bending during flight.

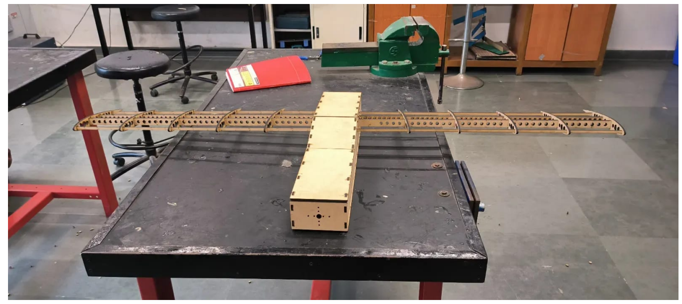

Fig. 5. Model of the aircraft(not prototype)

This model, constructed using laser-cut MDF sheets, was intended purely as a preliminary structural mock-up rather than a functional prototype. During its assembly, it was observed that the material was excessively heavy and the wing-forming strips exhibited significant flexing. However, this model proved valuable in helping us evaluate structural stability, component alignment, and construction feasibility before proceeding to the final design.

V. Propulsion System

A. Motor and Propeller Selection

Based on the estimated thrust requirement of approximately 3000g—corresponding to a thrust-to-weight ratio of around 0.5—1, a suitable brushless DC outrunner motor was selected due to its high thrust output and efficiency. From thrust data analysis, it was determined that the motor paired with a 10×5.5 propeller could deliver the required performance. However, as the 10×5.5 propeller was unavailable in the market, a 10×5 propeller was used instead, which exhibits comparable aerodynamic performance and thrust characteristics, ensuring minimal deviation in results.

Type	Propeller	Throttle	Voltage (V)	Current (A)	Power (W)	RPM	Torque (N*m)	Thrust (g)	Efficiency (g/W)	Operating Temperature (℃)
AS2814 Long Shaft KV1050	APC 10*5.5	40%	15.79	9.66	152.52	7248	0.136	827	5.42	92 (Ambient Temperature:/)
		45%	15.76	11.48	180.90	7657	0.157	944	5.22	
		50%	15.71	13.20	207.28	8033	0.172	1042	5.03	
		55%	15.66	15.24	238.67	8345	0.195	1165	4.88	
		60%	15.61	17.61	274.98	8747	0.216	1288	4.68	
		65%	15.55	20.21	314.22	9142	0.237	1423	4.53	
		70%	15.48	23.37	361.77	9605	0.263	1570	4.34	
		75%	15.39	27.38	421.30	10064	0.297	1752	4.16	
		80%	15.29	31.67	484.19	10506	0.326	1917	3.96	
		90%	15.06	41.60	626.63	11362	0.385	2251	3.59	
		100%	15.02	43.68	655.87	11446	0.399	2320	3.54	
	APC 11*5.5	40%	15.77	9.94	156.76	6967	0.150	899	5.73	79 (Ambient Temperature:/)
		45%	15.72	11.83	185.92	7367	0.171	1019	5.48	
		50%	15.68	13.73	215.24	7756	0.190	1108	5.15	
		55%	15.62	16.37	255.58	8053	0.226	1174	4.59	
		60%	15.56	19.09	296.92	8544	0.249	1359	4.58	
		65%	15.49	22.02	341.14	8950	0.275	1542	4.52	
		70%	15.40	25.78	397.04	9389	0.307	1742	4.39	
		75%	15.31	29.80	456.05	9824	0.338	1907	4.18	
		80%	15.19	34.88	529.96	10235	0.377	2106	3.97	
		90%	14.94	46.36	692.40	10917	0.450	2454	3.54	
		100%	14.89	48.22	718.16	11014	0.457	2474	3.44	
		40%	11.86	7.18	85.10	4968	0.108	616	7.24	
		45%	11.82	8.53	100.80	5308	0.123	701	6.96	
		50%	11.79	9.88	116.43	5612	0.136	773	6.64	
		55%	11.75	11.39	133.89	5880	0.152	871	6.51	

Fig. 6. Parameters that are specified for the motor and the propeller

B. Electronic Speed Controller (ESC) and Battery

An 80A Electronic Speed Controller (ESC) and a 5200mAh 14.8V Li-Po battery were selected to supply adequate current to the motor while aiming to achieve a flight time of approximately 10–15 minutes under typical cruising conditions.

VI. Control System

A. Control Surfaces

Elevators, rudder, and ailerons were used for pitch, yaw, and roll control respectively. Control horns and linkages were tested for responsiveness. These were sized according to an RC plane calculator and still looking for valid sizing from other reliable sources.

B. Radio Transmitter and Receiver

A 6-channel radio system was used to operate all essential control functions during manual flight testing.

VII. Manufacturing and Assembly

A. CAD Modeling

3D CAD models of the wing and fuselage were created using Fusion 360. The parts were optimized for modularity and ease of printing or cutting.

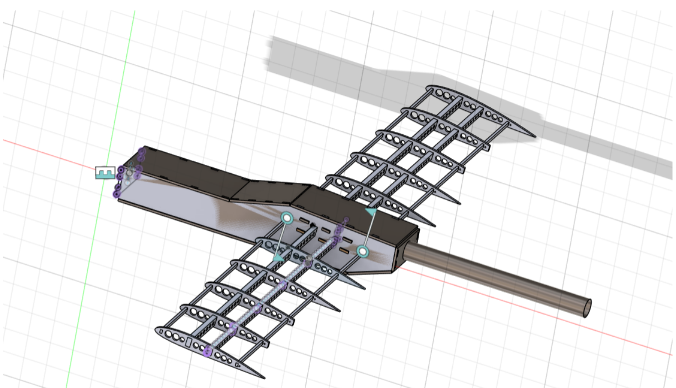

Fig. 7. Orthogonal view of the model

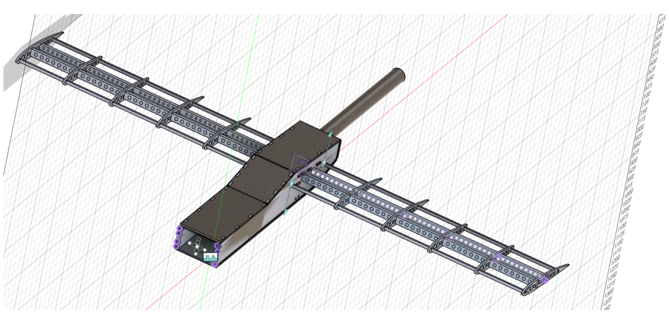

Fig. 8. Front orthogonal view

The CAD model was initially designed with laser cutting-based manufacturing in mind, optimized for sheet-based construction and slot-fit assembly. The wing was first designed to be fixed onto the fuselage; however, during testing it was observed that the wing was flexing significantly. Since the wing is critical to flight performance, it was later decided to reverse the approach—designing and constructing the wing first for improved rigidity, and then integrating it into the fuselage to ensure better structural support and alignment. Additionally, it was realized that the initial shape was not ideal for the final prototype, prompting a shift to a different manufacturing method more suited for aerodynamic accuracy and strength.

To minimize the overall weight of the aircraft, a lightweight pipe was used for the fuselage section behind the wing, onto which both the horizontal and vertical stabilizers would be mounted at its end.

B. Fabrication Process

Laser cutting and 3D printing were used to fabricate components for the model. Adhesives and mechanical fasteners were used during assembly.

C. Ground Testing

Although full ground testing has not yet been conducted, preliminary structural assessments were carried out on a laser-cut MDF model. These tests involved manual loading of the wing to observe flexing behavior and identify weak points in the structure. This helped in understanding the limitations of certain material choices and highlighted the need for a more robust wing design in the final prototype.

D. Flight Testing

Flight testing has not been performed as the final prototype is still under construction. However, expected flight characteristics and performance metrics have been simulated using XFLR5, which provided insight into lift, drag, and stability parameters. Once the refined prototype is completed with appropriate materials and integrated control systems, a comprehensive flight test plan will be developed.

VIII. Future Work and Modifications

While the current design meets the initial objectives, several improvements and future applications can be explored:

- **Feasible Prototype Development:** Build a refined prototype using optimized lightweight materials to enhance structural performance. Integrate a flight controller such as Pixhawk to enable stable and autonomous flight operations. Design the airframe to include modular space for payload expansion and onboard sensors such as environmental modules or cameras. Additionally, explore converting the current layout into a hybrid fixed-wing configuration with a rear-mounted (pusher) propeller and a raised T-tail assembly to improve aerodynamic efficiency and stability.

References

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