KLS GOGTE INSTITUTE OF TECHNOLOGY

Belagavi, Karnataka

TECHFEST 2024

Fixed Wing Design Report

Team ID: Aero-230514

TEAM OCTAKNIGHT

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1. Introduction

This document presents the final design developed by Team OctaKnight from KLS Gogte Institute of Technology, Belagavi, for the upcoming TECHFEST 2024. The purpose of this Fixed-Wing Unmanned Aerial Vehicle (UAV), named "KESTREL," is to demonstrate superior capabilities in long- endurance flight and stable performance over extended distances. Optimised for missions requiring precise navigation and payload delivery, KESTREL is designed to operate effectively in varying weather conditions and large coverage areas. With a focus on endurance, range, and aerodynamic efficiency, the UAV's fixed-wing structure enhances its stability and speed during flight. The main objective is to meet the mission requirements outlined by TECHFEST 2024, while ensuring safety, reliability, and mission success. This report details the methodology, design, aerodynamics, and performance of KESTREL, illustrating its potential to set new benchmarks for fixed-wing UAV applications.

1.1 Objective

The main objective of participating in TECHFEST 2024 is to push the boundaries of fixed-wing UAV technology, demonstrating our creativity and technical expertise. This competition is not merely an event but a journey toward innovation and excellence. It offers a unique opportunity to contribute to cutting-edge advancements while being inspired by the remarkable work of our peers. Through this experience, we seek to sharpen our skills in design, development, problem-solving, and teamwork, equipping ourselves for the challenges of tomorrow. Engaging with industry professionals and fellow enthusiasts will broaden our perspectives and foster future collaborations and opportunities. Our goal is not only to gain recognition but to highlight our dedication to advancing UAV capabilities and redefining what is possible.

1.2 Problem Statement

The problem statement suggests the development of UAS which can carry a specified payload and deliver it to a target through both manual and autonomous operations. The payload will be golf balls.

SI.No.	Parameter	Requirement/Limitation
1	UAS Type	Fixed wing
2	UAS Category	Micro UAS (Take-off weight < 3kg)
3	Payload Capacity	300g-500g
4	Propulsion Type	Electric
5	Communication System Range	At least 1 km

Table no 1.2.1: UAS Design Requirements

2. Design Specifications

2.1. Detailed CAD model

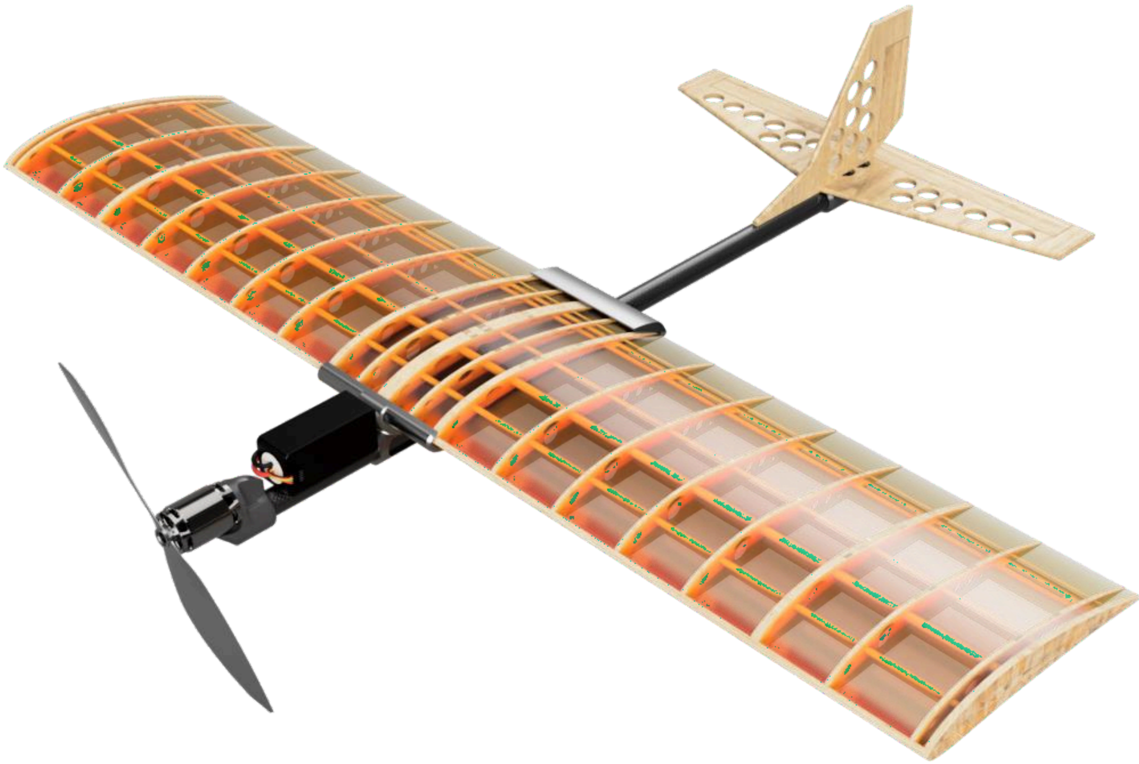


Fig. No. 2.1.1: CAD model of the Aircraft

The aircraft features a moderate-sized airframe with a wingspan of 1 meter and a chord length of 23cm, yielding an aspect ratio of approximately 4.3. The design incorporates a 3-degree dihedral angle in the wing, enhancing lateral stability during flight. The fuselage, constructed from a single carbon composite fibre (CCF) tube measuring 70 cm in length, offers an excellent combination of structural rigidity and minimal weight. A notable design choice is the high-mounted electric motor position above the fuselage centreline, which provides adequate ground clearance for the propeller. The high-wing configuration, combined with the dihedral angle, promotes inherent stability characteristics desirable for steady flight performance. The wing's internal structure follows a traditional balsa rib-and-spar construction method, covered with a lightweight transparent film that allows visual inspection of the structural components while maintaining aerodynamic efficiency. This combination of materials and design parameters results in an aircraft that balances performance requirements with structural efficiency, while keeping construction complexity manageable.

2.2 Detailed Weight Breakdown

Component name	Weight per pc (g)	quantity	Total weight (g)
T-motor AT2820 880kv motor	139	1	139
T-motor AT 55A 6S ESC	63	1	63
1145 APC propeller	20	1	20
MG90s servo	13	5	65
RadioMaster ER5C ELRS Receiver	6.6	1	6.6
CNHL 1500mah 4S battery	174	1	174
Wing	215	1	215
Fuselage	360	1	360
Wires and connectors	25	1	25
Payload	500	1	500
Total Weight (g)			1561

Table no 2.2.1: Detailed Weight Breakdown

2.3 Power Required for the mission.

Considering a minimum thrust to weight ratio of 0.5:1 for straight and level flight, the current draw of the motor would be:

$$With\ Payload\ = 8.76A$$

$$Without\ Payload\ = 6.3A$$

$$Current\ Draw\ of\ other\ avionics = 0.8A$$

Endurance without payload:

$$Flight\ time = \frac{Capacity \times Discharge}{Average\ amp\ draw} = \frac{1.5 \times 0.95}{7.1} = 0.2007$$

Therefore,

$$\boldsymbol{Flight\ time = 12.04\ minutes.}$$

Endurance with payload:

$$Flight\ time = \frac{Capacity \times Discharge}{Average\ amp\ draw} = \frac{1.5 \times 0.95}{9.56} = 0.1490$$

Therefore,

$$\boldsymbol{Flight\ time = 9.34\ minutes.}$$

3. Aerodynamic Analysis

The aerodynamic analysis of an airfoil reveals its balance between lift and drag, crucial for efficient performance across various angles of attack (AoA). Airfoils with moderate camber and thickness generate sufficient lift at low to moderate AoA while minimizing drag, which is essential for applications requiring both energy efficiency and stable flight. A stable lift-to-drag (CL/CD) ratio ensures consistent aerodynamic performance, whether in cruising conditions or during manoeuvres. Furthermore, smooth stall characteristics contribute to better control and handling, especially at lower speeds or near stall, which is vital for applications like UAVs that rely on precise, controlled flight dynamics.

3.1. Airfoil Selection

We are selecting the NACA 4412 airfoil due to its well-balanced performance characteristics that make it an optimal choice for a variety of UAV applications. The NACA 4412, with its 4% camber, 40% camber location, and 12% thickness, offers an excellent balance between lift generation and drag minimization, which is critical for UAVs requiring both efficient cruising and reliable takeoff/landing performance. Compared to other high-lift airfoils, such as the NACA 23112 or NACA 6412, the NACA 4412 offers a more manageable stall behavior. While airfoils like the 23112 may offer slightly higher maximum lift coefficients, they tend to exhibit more abrupt stall characteristics, which can be risky in tight manoeuvring situations or when operating near stall speed. The 4412's smooth stall behaviour ensures that the UAV will maintain better control and handling at low speeds, which is critical in scenarios such as payload drops or low-altitude flight.

In terms of drag, the NACA 4412 offers a low drag coefficient at moderate angles of attack, making it well-suited for UAV missions that require endurance and energy efficiency. When compared to other high-lift airfoils like the NACA 6412, which has higher camber and thus higher lift potential, the 4412 provides a better compromise between lift and drag, ensuring longer flight times while still offering sufficient lift for typical UAV payloads. Additionally, the thicker trailing edge of the NACA 4412 contributes to structural robustness, a vital feature for UAVs that may face turbulence or gusty wind conditions.

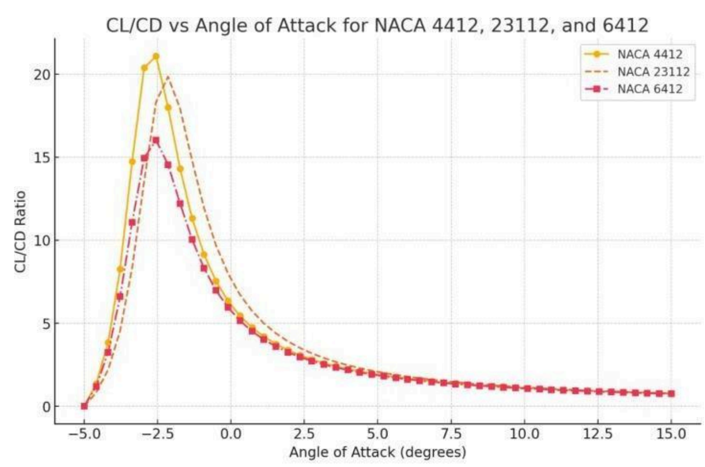


Fig. No. 3.1.1: CL/CD vs AoA for NACA 4412, 23112, 6412

Here is a graph comparing the lift-to-drag ratio (CL/CD) of the NACA 4412, NACA 23112, and NACA 6412 airfoils across various angles of attack (AoA). As shown, the NACA 4412 exhibits a well-balanced CL/CD ratio, performing effectively across a broad range of AoA. It maintains strong lift generation with moderate drag, while the NACA 23112 shows lower CL/CD values, and the NACA 6412, although offering higher lift, has a steeper drag penalty at higher angles of attack. This balance makes the NACA 4412 a great choice for UAV applications.

3.2. CG Analysis

Centre of Gravity (CG) analysis is critical for optimizing the stability and control of a UAV using the NACA 4412 airfoil. Based on the CL/CD data for the 4412, which demonstrates a well-balanced aerodynamic performance across a wide range of angles of attack (AoA), proper CG placement becomes essential. For this airfoil, placing the CG slightly ahead of the centre of pressure ensures that the UAV remains stable, especially during cruising and low-speed operations. The forward CG position promotes stability but can lead to slightly increased drag, requiring more lift from the tail, which the NACA 4412 can handle efficiently due to its smooth lift generation and moderate drag profile.

Given the predictable stall characteristics of the NACA 4412, the CG should be placed to prevent excessive pitching or sudden stalls during critical manoeuvres. This is especially important during low-speed operations such as landing, takeoff and payload delivery, where improper CG placement could lead to control issues. The airfoil's stable performance at various AoA suggests that the CG can be positioned to optimize both stability and control without sacrificing manoeuvrability. This balanced CG placement ensures that the UAV benefits from the NACA 4412's aerodynamic efficiency, enhancing flight endurance, stability, and overall performance.

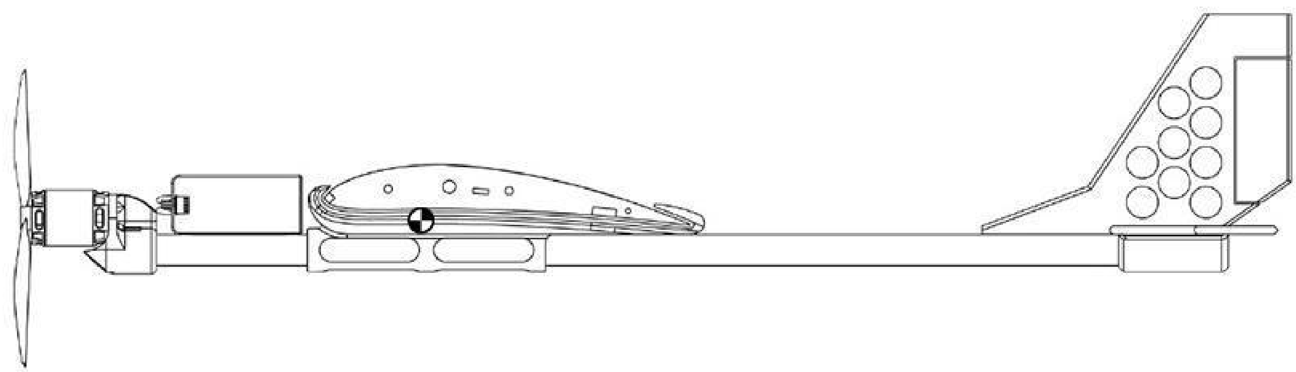


Fig No. 3.2.1: CG Analysis

4. Subsystem Selection

4.1. Propulsion System

The AT2820 3D F3A Fixed Wing Long Shaft Fixed Wing UAV Motor has been chosen for several technical reasons. Each motor must provide a hover thrust of 750 grams to achieve stable flight. This motor meets that thrust requirement within its most efficient throttle range, ensuring optimal power usage and extended flight times. Its high torque and power output are crucial for maintaining stable flight with additional payloads in adverse weather conditions. The motor delivers optimal efficiency when paired with 9-inch propellers, which are ideally suited for the aerodynamic design of our frame. Lastly, the motor's self-cooling design helps prevent overheating, ensuring reliable performance during extended operations.

Fig no. 4.1.1: AT2820 3D F3A Long Shaft Fixed Wing UAV Motor Fig. No. 4.1.2: Glass Fiber Nylon Propeller

The 1045 glass fiber nylon propellers have been chosen for their compatibility with the motor and the frame. Its rolled carbon fiber build makes it light weight compared to other APC propellers of similar size while not compromising durability.

Fig No.4.1.3: T-Motor AT 55A 6S ESC

We are using the T-Motor AT 55A 6S ESC in our fixed-wing UAV for its high efficiency and precise control. With a 55A continuous current rating and 6S LiPo compatibility, it delivers consistent power for our motor, ensuring stable flight performance. Its lightweight design minimizes UAV weight, while features like active braking improve responsiveness during maneuvers. The ESC's reliability under high load conditions ensures optimal performance during long endurance flights, making it an ideal fit for our power and control needs.

4.2. Control Link

We selected the Radiomaster TX16S MKII HALL V4.0 ELRS Radio with the RP1 ExpressLRS 2.3 GHz Nano Receiver and RadioMaster ER5C 5Ch ELRS PWM Receiver for its use of the ExpressLRS (ELRS) communication protocol, which ensures ultra-low latency and high range, critical for precise UAV control. The ELRS protocol operates in the 2.4GHz band, offering robust, interference-resistant communication, ideal for long-range and stable signal transmission. We are utilizing 5 channels: the first four control throttle, ailerons, elevator, and rudder, while the fifth channel is dedicated to payload dropping. This setup provides efficient control and reliable communication for all key functions of the UAV, ensuring smooth operation throughout the mission.

4.3. Power System

Fig. No.4.3.1: Lithium Polymer Battery

We're using the CNHL Black Series 1500mAh 14.8V 4S 100C LiPo Battery for its high-power output and lightweight design, making it ideal for our UAV's performance needs. With a 100C continuous and 200C burst discharge rate, we get reliable power for demanding manoeuvres, while the 4S 14.8 configuration ensures stable voltage for efficient operation. At just g, it perfectly balances weight and power, optimising our flight performance.

5. Payload Dropping mechanism

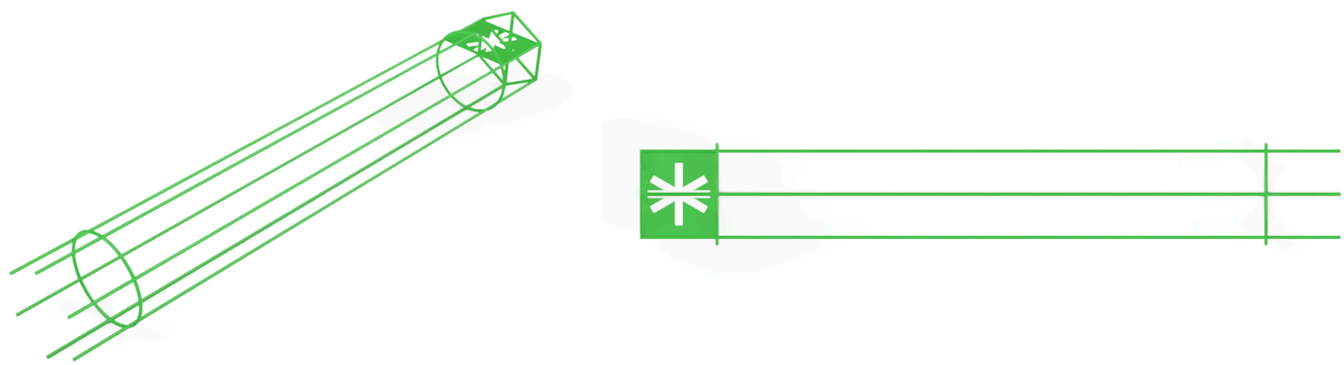


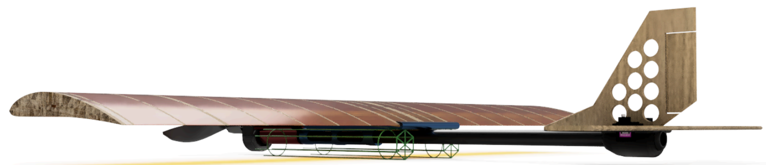
Fig. No.5.1 & 5.12: Payload dropping mechanism

Using the given payload of golf balls, a rail-mount has been made in which the payload will be accommodated. The mount has a one way entrance to allow the balls in, and a servo operated exit that lets the balls out.

The servo motors are held in place by a structure attached to the fuselage.

When it is time to drop the payload, the semi-circular arms will rotate 180° and release the payload.

5.1. Payload Integration Into Assembly



6. Final UAS Specifications

Parameter	Value
Wingspan	1000mm
Fuselage Length	700mm
Empty weight	1061g
Max take-off weight	1561g
Max thrust	1003g
Maximum endurance with payload	9.34 minutes
Maximum endurance without payload	12.04 minutes
R/C communication frequency	2.4 GHz
Max Control transmission range	5 km
Battery type	Lithium Polymer
Battery voltage	25.2 volts
Battery capacity	1500 mAh
Failsafe features	Throttle to 0%, Glide trim with slight left rudder.

Table no 6.1: UAS Specifications

7. Building & Testing:

8. Bill of Materials

SR No.	Component Name	Quantity	Single Unit Price	Total Quantity Price	Manufacturer
4	TX16S RC transmitter	1	₹ 18,999.00	₹ 18,999.00	Robu
	Total			**₹18,999.00**	

Table no 4.2: Bill of material for Ground Station Components

SR No.	Component Name	Quantity	Single Unit Price	Total Quantity Price	Manufacturer
1	T-motor AT2820 880KV motor	1	5,043.22	5043.22	T-Motor
2	T-motor AT 55A 6S ESC	1	2,773.00	2773.00	T-Motor
3	1145 APC propeller	1	199.00	199.00	Orange HD
4	MG90s servo	1	199.00	995.00	TowerPro
5	CNHL 1500mAh 4S battery	1	1,999.00	1999.00	CHNL
6	RadioMaster ER5C ELRS Receiver	1	2,429.32	2,429.32	RadioMaster
7	Balsa Wood Sheets/Dowels	1	2000.00	2000.00	Offline Vendor
8	Roll-Wrapped Carbon Fiber Tube	1	1469.00	1469.00	Robu
	Total			**16,907.54**	

Table no 4.3: Bill of Material for Aircraft Components

References:

- *NACA 4412 (NACA4412-IL)*. Available at: http://airfoiltools.com/airfoil/details?airfoil=naca4412-i.
- *CNHL Black series 1500mah 22.2V 6s 100C lipo battery with XT60 Plug ChinaHobbyLine*. Available at: https://chinahobbyline.com/products/cnhl-black-series-1500mah-22-2v-6s-100c-lipo-battery-with-xt60-plug.
- *AT2820 3D F3A fixed wing long shaft fixed wing UAV motor-KV880/KV1050/KV1250_AT series_motors_vtol/fixed wing power_t-motor official store-multi-rotor UAV,fixed wing,VTOL,FPV and robot power_AT Series_Motors_VTOL/Fixed Wing Power_T-MOTOR Official Store-Multi-rotor UAV,Fixed Wing,VTOL,FPV and Robot Power*. Available at: https://store.tmotor.com/product/at2820-long-shaft-fixed-wing-motor.
- *TMOTOR AT55A 2-6s fixed wing ESC for Outdoor Aircraft T*. Available at: https://shop.tmotor.com/products/fixed-wing-esc-at55a-2-6s.