Radio-Controlled Butterfly (Biomimetic Ornithopter) Research & Development Report

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1. Abstract

The Radio-Controlled Butterfly Project aims to design and develop a lightweight biomimetic ornithopter that replicates the flapping-wing flight mechanism of a butterfly. Inspired by natural flight systems, this project explores aerodynamic efficiency, mechanical simplicity, and bio-inspired engineering design to create a functional remote-controlled prototype.

With the growing global interest in micro-air vehicles (MAVs), bio-inspired drones, and defence applications that demand silent, efficient, and maneuverable flying systems, this project provides SAST an opportunity to establish foundational expertise in advanced aeromechanics. The goal is to engineer a stable, controllable, and efficient butterfly-like flapping mechanism capable of sustained flight and suitable for demonstration, research, and future innovation.

2. Introduction

2.1 Background

An ornithopter, traditionally, is an aircraft that imitates the flight of a bird by using the same wing-flapping mechanism that birds and other flying animals use in their flight. A butterfly-inspired biomimetic ornithopter similarly uses the same flight mechanism as a typical butterfly. Different from a bird-inspired ornithopter, a this ornithopter uses a butterfly's unusual and sophisticated aerodynamic "tricks" like clap-and-fling mechanism that generate powerful jet that help in rapid take off and quick escape and low Reynolds numbers (2,500 to 12,600) that makes viscous forces dominate over the inertial forces that leads to better laminar flow, i.e better lift and reduced drag in flight. Inspired by butterflies' lightweight, flexible and membrane-based wings that aid in delayed stall effects at high angles, this approach offers distinct advantages that include, but are not limited to: exceptional maneuverability, silent operation, reduced energy consumption at low speeds, and the ability to hover or perform vertical takeoff.

A butterfly is an ideal model for low-speed, efficient flight ornithopter and has the potential to become an efficient MAV(Micro Air Vehicle) for not just defence and surveillance use, but also for scientific research and environmental monitoring due to its efficiency in cluttered environments, silent operation, and exceptional agility.

2.2 Motivation

The challenge is to develop a stable, remote-controllable ornithopter that has low mass and a reliable enough wing design that can sustain the mimicking of the sophisticated and complex maneuvering and flight techniques and patterns of a typical butterfly.

This project aims to:

- Promote innovation through hands-on research in biomimetic flight and micro-aviation systems.
- Build a culture of engineering excellence and teamwork that is driven by technical exploration & curiosity.
- Develop skills and have a hands-on experience in aerodynamics, mechanical design, electronics integration, and control systems.

3. Project Objectives

3.1 SAST Objectives

- Strengthen SAST's position as a leading student-driven aerospace and space technology society.
- To attain measurable outcomes:
    - Successful development and testing of at least one functional RC butterfly
    - A working prototype.
    - Participation in at least one internal or external technical showcase.
    - Expansion of the R&D portfolio in advanced flight systems.

3.2 Technical Objectives

- Design and construct a flapping-wing mechanism that can mimic butterfly flight patterns and techniques.
- Achieve stable flight (at least 45–60 seconds flight time) with controlled rapid take-off, jet-thrust, and agile maneuverability.
    - Demonstrate at least three successful test flights.
- Maintain low structural mass (target < 350 g) through optimized, sustainable materials and creative design.

- Document the engineering, research and development process, iterations, and testing results.

4. Biological Flight Study

4.1 Butterfly Wing Kinematics

Butterfly wings twist, bend, rotate, and clap together during each stroke due to their unique structure.

- Flapping frequency: About 5 to 20 beats per second, due to their large wing area.
- Wing rotation: Wings tilt during the downstroke to push air downward for thrust and lift, and often rotate on the upstroke to reduce drag.
- Clap-and-fling: Butterflies clap their wings together at the end of their upstroke, pressing air out to create a powerful jet, thrusting them forward and upward, which helps in rapid vertical take-off and quick escape.

4.2 Aerodynamic Principles

Butterflies fly at 2,500 to 12,600 Re (Reynold Number) where air behaves thickly, and usual aerodynamics doesn't apply. Instead, they rely on unsteady aerodynamics.

- Flexible wings: Their wings deform and reform, improving lift and reducing drag in flight. Guiding our material of choice (mylar film and light spars).

- Vortex generation**:** Each flap produces swirling air structures that increase lift, maneuverability and agility.

5. Strategy

5.1 Approach

The project will follow a structured development cycle beginning with biological flight research, followed by CAD modelling, mechanical fabrication, electronics integration, and iterative flight testing.

The team will:

- Study existing butterfly wing mechanics and MAV research.
- Develop mechanical linkages suitable for controlled flapping.
- Use lightweight materials such as balsa, carbon fibre, or mylar to ensure aerodynamic performance.
- Integrate micro-motors, a LiPo power system, and an RC receiver.
- Test, refine, and optimize through repeated trials.
- This approach ensures that the design is feasible within the project timeline and achievable with available resources.

6. System Requirements

5.1 Functional Requirements

ID	Requirement	Target Value
FR-01	The prototype must generate sufficient lift for sustained flight	≥ 45 seconds
FR-02	The butterfly wing clap mechanism must produce a powerful enough jet thrust for forward and upward motion.	Continuous
FR-03	RC control must allow turn, climb, descent, maneuver and demonstrate delayed stall effects.	Basic stability and agility

6.2 Non-Functional Requirements

ID	Requirement	Target Value
NFR-01	Total system mass	≤ 350 g
NFR-02	Structural durability vs weight	Optimized bamboo + composite frame
NFR-03	Power efficiency	≥ 1 minute flight per charge
NFR-04	Ease of fabrication	Components manufacturable with basic tools

6.3 Design Constraints

- Weight limitations due to low Reynolds number flapping flight
- Limited structural stiffness from lightweight materials
- The wing area trade-off due to the use of a motor to generate torque for flight.
- Fixed budget for student-level R&D

6.4 Budget Summary

Component / Material	Cost (₹)
F949 Flight Controller	₹3,000
Brushless Motor	₹2,893
LiPo Battery	₹303
Bamboo Sticks (structural frame)	₹200
Miscellaneous (sheets, tape, adhesive, wing film)	₹1,000
Wing Material + Spar Rods	₹300
Transmitter + Receiver	₹0 (Already available)