Mechanical Design Portfolio

Harsh Jashvantbhai Modi

PROJECT 1: MorphoCopter: Transformable Aerial Vehicle

Skills: Mechanical design, prototyping, fixtures, testing, failure analysis

Problem & Constraints

Traditional drones have a large size compared to payloads and cannot access spaces with narrow passages. Existing designs on this problem use complex multi-joint actuation, do not achieve enough size reduction, lose control in a narrow configuration and/or require complex maneuvers for narrow gap traversal. The goal of this project was to design a **mechanically simple aerial vehicle capable of mid-flight reconfiguration** to drastically reduce its footprint while remaining flight-worthy.

Key constraints:

- Structural integrity under flight loads
- Minimal added mass and complexity
- Repeatable transformation on the fly without compromising reliability

Design & Tradeoffs

I designed a **servo-actuated transformable quad-bi-copter** that reduces its width on the fly from **450 mm to 150 mm (or any size in between)** using a single mechanical joint. I explored multiple concepts before selecting a **single-actuator solution** to minimize weight, failure points, and assembly complexity.

Key mechanical considerations:

- Joint geometry and load paths during transformation
- Full control in the narrowest configuration
- Stiffness vs. weight tradeoffs in structural members
- Actuator sizing based on worst-case aerodynamic and inertial loads

Build & Prototype

I modeled the full system in CAD, designed custom mechanical parts, and fabricated prototypes using additive manufacturing and laser cutting. I assembled the complete airframe, integrated propulsion components, and iterated on tolerances to ensure smooth and repeatable motion.

Test & Validation

To reduce risk before flight:

- Designed and built a **custom motor thrust test fixture** to characterize propulsion performance
- Conducted repeated transformation tests to evaluate mechanical repeatability
- Conducted simulations with Gazebo first to find out code failures

Failures & Iteration

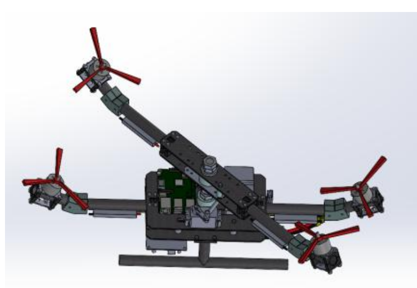
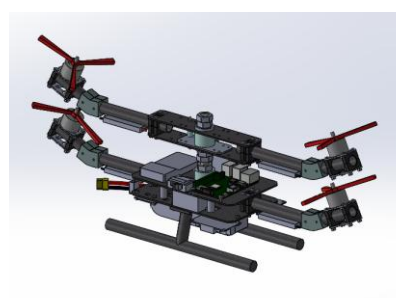
Early prototypes suffered from joint compliance and vibration under load. I addressed this by:

- Completely redesigning the load-bearing joint
- Integrating 4-bar mechanism for servo motor actuation to physically limit rotation and enhance mechanical leverage.

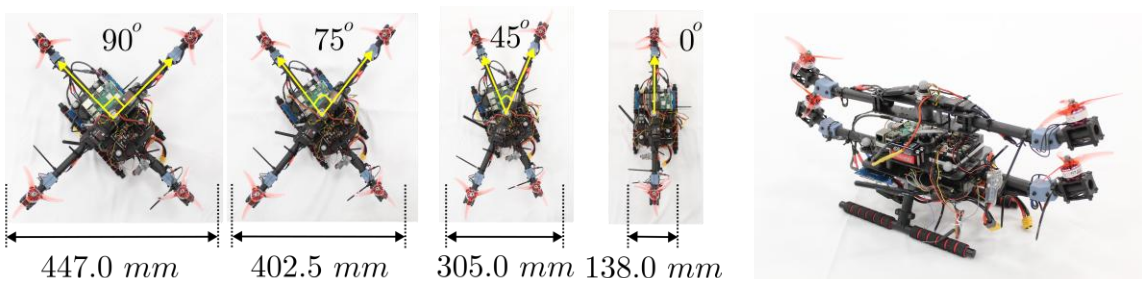
Outcome

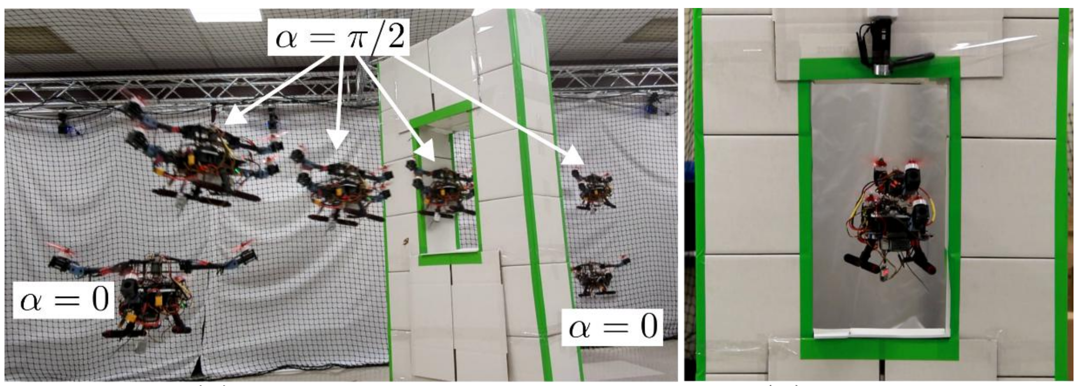
- Successfully demonstrated repeatable mid-flight transformation
- Even in a few crashes (while trying new trajectories), it survived
- Design resulted in a **US provisional patent** and an **accepted journal publication**

CAD design:

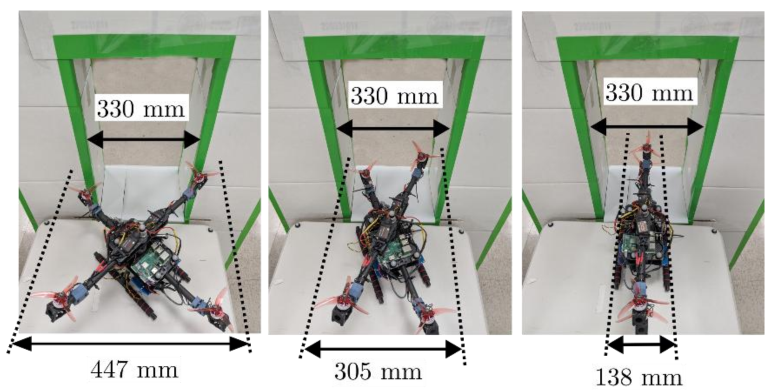




Hardware photographs:





(a) Isometric View (b) Front View



Experiment videos:

https://www.youtube.com/watch?v=-Cgr8RbE3Ko

PROJECT 2: Electric Propulsion & Motor Thrust Test Fixture
Skills: Mechanical design, test rigs

Objective

To objectively evaluate **motor–propeller combinations** and eliminate guesswork during propulsion selection, I designed a **repeatable motor thrust test fixture**.

Design & Build

I designed a rigid fixture to:

- Securely mount motors and propellers along with actual UAV arm
- Isolate thrust forces with minimal aerodynamic effects of the ground
- Minimize vibration and measurement error

The fixture was fabricated and assembled in-house and designed for quick motor swaps.

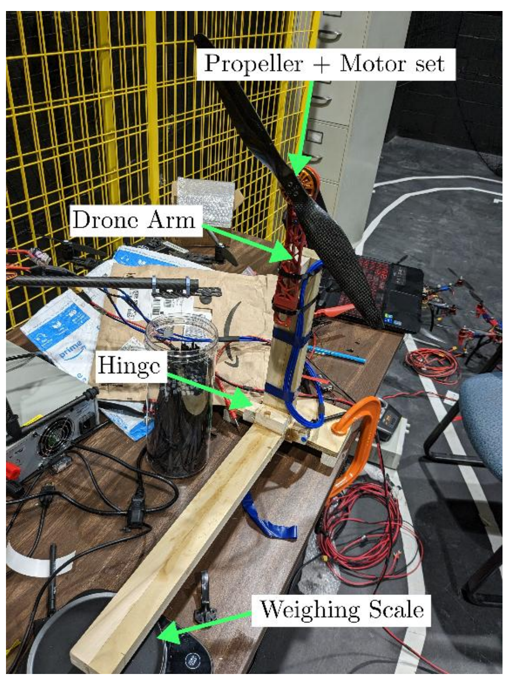
Instrumentation & Testing

The setup allowed measurement of:

- Static thrust
- Current and voltage
- Thermal behavior
- Efficiency trends across operating points

Tests were run across multiple motor-propeller configurations to guide design decisions. This fixture directly informed propulsion selection for flight vehicles.

Hardware photograph:



PROJECT 3: VTOL Transition Mechanism (NTU Singapore)

Skills: Mechanism design, structural analysis, manufacturing

Problem

Design a **mechanically reliable transition mechanism** for a VTOL fixed-wing UAV that could withstand flight loads while remaining compact and lightweight.

Design & Analysis

I developed multiple mechanism concepts and performed:

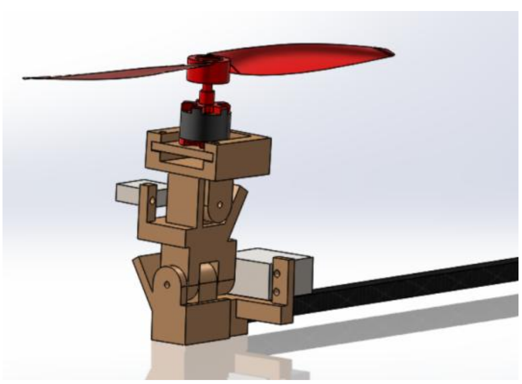
- **Structural sizing and stress analysis in ANSYS**
- Load case evaluation for hover and forward flight
- Trade studies to balance stiffness, weight, and simplicity

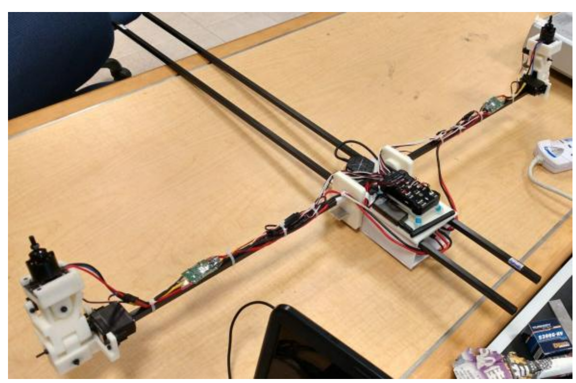
Build & Test

The final design was manufactured using additive manufacturing and assembled with off-the-shelf UAV components. Ground and bench testing validated:

- Smooth transition behavior
- Structural integrity under expected loads

CAD design and hardware photographs:





PROJECT 4: Energy Storage via Pendulum Oscillations on UAV
Skills: PX4, CAD, Repeatability testing

Objective

Explore whether a UAV could **store kinetic energy mechanically** using an unactuated pendulum and release it for a targeted task.

Mechanical Challenges

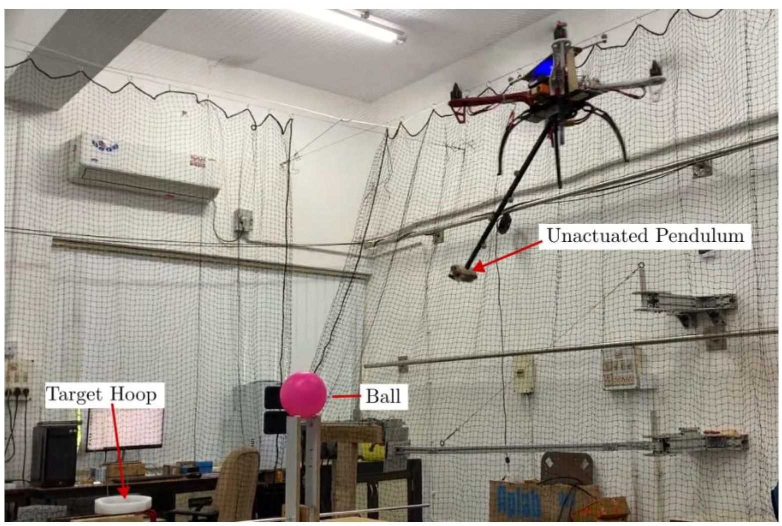
- Managing oscillation growth without destabilizing the vehicle
- Ensuring mechanical repeatability across trials
- Coupling vehicle motion to pendulum dynamics safely

Testing & Results

Through controlled experiments, I achieved:

- Gradual energy accumulation
- **~90% repeatability** in hitting the ball and passing it through the target hoop

Experiment snapshot:



Experiment video:

https://youtu.be/NHGj9HEucaE?feature=shared

PROJECT 5: Servo-Actuated Object Drop Mechanism for UAV
Skills: Mechanism design, rapid prototyping, actuation, integration

Problem & Constraints

A UAV required a **simple, reliable mechanism** to release a payload on command during flight. The solution needed to be lightweight, compact, easy to manufacture, and compatible with standard UAV servos, while minimizing mechanical complexity and failure risk.

Design & Tradeoffs

I designed a **servo-actuated rack-and-pinion mechanism** to convert rotational servo motion into controlled linear release of the payload. This approach was selected over linkage-based designs to ensure predictable motion, straightforward integration, and minimal part count.

Key considerations included:

- Actuation force vs. servo torque limits
- Compact packaging within the UAV frame
- Avoiding unintended release due to vibration

Build & Prototype

The mechanism was fully modeled in CAD and **manufactured using 3D printing** for rapid iteration. Components were designed to be easily assembled and integrated onto an existing UAV without requiring structural modifications.

Test & Validation

Bench testing verified:

- Reliable actuation and release on command
- No accidental release under vibration and handling
- Smooth engagement and disengagement of the rack-and-pinion interface

Outcome

The final mechanism successfully enabled **on-demand payload release** during UAV operation and was deployed to support flight experiments during my internship at NTU Singapore. The design demonstrated how **simple mechanical solutions** can meet functional requirements with minimal risk and development time.