Design and Development of Cyclorotor for Parametric Study of Thrust Vectoring

Introduction

A cyclorotor, also known as a cycloidal rotor, is a unique propulsion system that generates lift and thrust through the cyclic motion of its blades, which rotate around a horizontal axis. The blades change their pitch angle cyclically during each rotation. This unique mechanism allows for precise control of thrust direction and magnitude, making cyclorotor highly maneuverable. They are used in various applications, including vertical take-off and landing (VTOL) aircraft, drones, and marine propulsion systems, due to their ability to provide exceptional control and stability. Advances in materials, control systems, and computational modeling have significantly improved cyclorotor performance, making them a versatile and promising technology for future innovations.

Project Objective

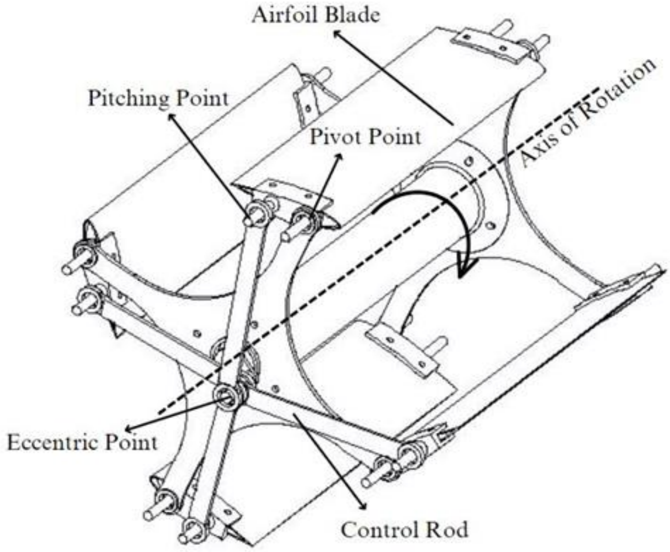
The exploration of efficient propulsion systems has led to a resurgence of interest in cyclorotor due to their low-noise lift generation and precise 360° thrust vectoring capabilities. Despite its significant potential, advancements in materials, control systems, and blade design remain active areas of research. Efforts have been made to optimize blade design, and successful flights have been achieved, but the control strategy for stable flight characteristics is still under development. Understanding the control of thrust vectors is crucial for these strategies, necessitating experimental studies in real environments. This project is dedicated to experimentally studying the thrust vector to understand its relationship with the phase angle of eccentricity. Accurate knowledge of the thrust vector's behavior in relation to the phase angle of eccentricity allows for the development of more precise and robust control strategies and fine-tuning for better stability and maneuverability.

Implementation Details

Obtaining accurate data requires an optimally operating system and a well-defined environment. Cyclorotor contains various parts such as: blade, rotor wheel and control rods which have significant role in optimal operation of the system hence it is very important to consider design of each part of the system wisely.

Cyclorotor Design

Cyclorotor blades are responsible for generating lift at various instant during its rotation hence both upper and lower surface of the airfoil blade will produce lift during rotation. For this reason, the airfoil must be symmetrical. The optimal airfoil design noted from previous experiment is NACA0015 with blade pitch varying up to 40°, 2-inch chord, 3-inch rotor radius and 6.25-inch blade span generating thrust per unit blade span as 8N/m (Benedict, Jarugumilli, & Chopra, 2013). The pitching position on the airfoil was set to 25% percent of the chord length from the leading edge of the airfoil (Shrestha, Yeo, Benedict, & Chopra, 2017).



S.N.	Parameter	Value
1	Rotor Diameter	152.4 mm (6 inch)
2	Effective Blade Span	6.25 inch
3	Chord Length	50.8 mm (2 inch)
4	Pitching axis location	25% of chord from leading edge
5	Pivot point in airfoil	17.5 mm from Pitching axis
6	Total length of control rod	76.2 mm
7	Carbon Rob Spar Diameter	4 mm

Transmission System

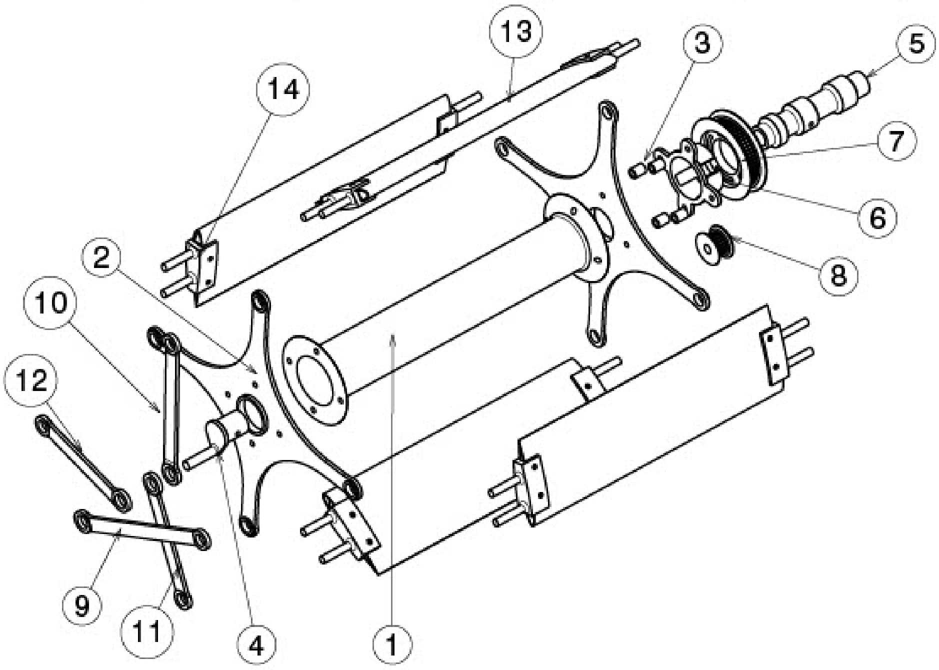
A brushless 1400 KV motor is used with gear reduction of 3 times using the GT2 timing belt pulley system. The motor was driven by 30A ESC, powered by 3S battery generating maximum RPM of 15540 RPM. The speed was controlled using a servo tester. A 200 mm closed loop GT2 timing belt was used for power transmission from the motor to the rotor wheel.

Manufacture and Fabrication

All the parts required were 3D printed using PLA material. The infill percentage for the airfoil was set to 10 % for reducing its weight whereas the components bearing high stresses were printed with 80% infill with zig-zag pattern. The assembly process involved joining parts temporarily using nuts and bolts and bearings were pressed for interference fit on the rotor wheel.

Bill of Material: Cyclorotor

Part No.	Part Name	Quantity
1	Main Separator Shaft	1
2	Rotor Main Wheel	2
3	Pulley Separator	4
4	Servo Coupler (outboard)	1
5	Servo Coupler (inboard)	1
6	Gear Coupler	1
7	GT2 60T Timing Pulley	1
8	GT2 20T Timing Pulley	1
9	Control Rod 4	1
10	Control Rod 1	1
11	Control Rod 2	1
12	Control Rod 3	1
13	Airfoil Blade (2in)	4
13	Airfoil Holder (2in)	8



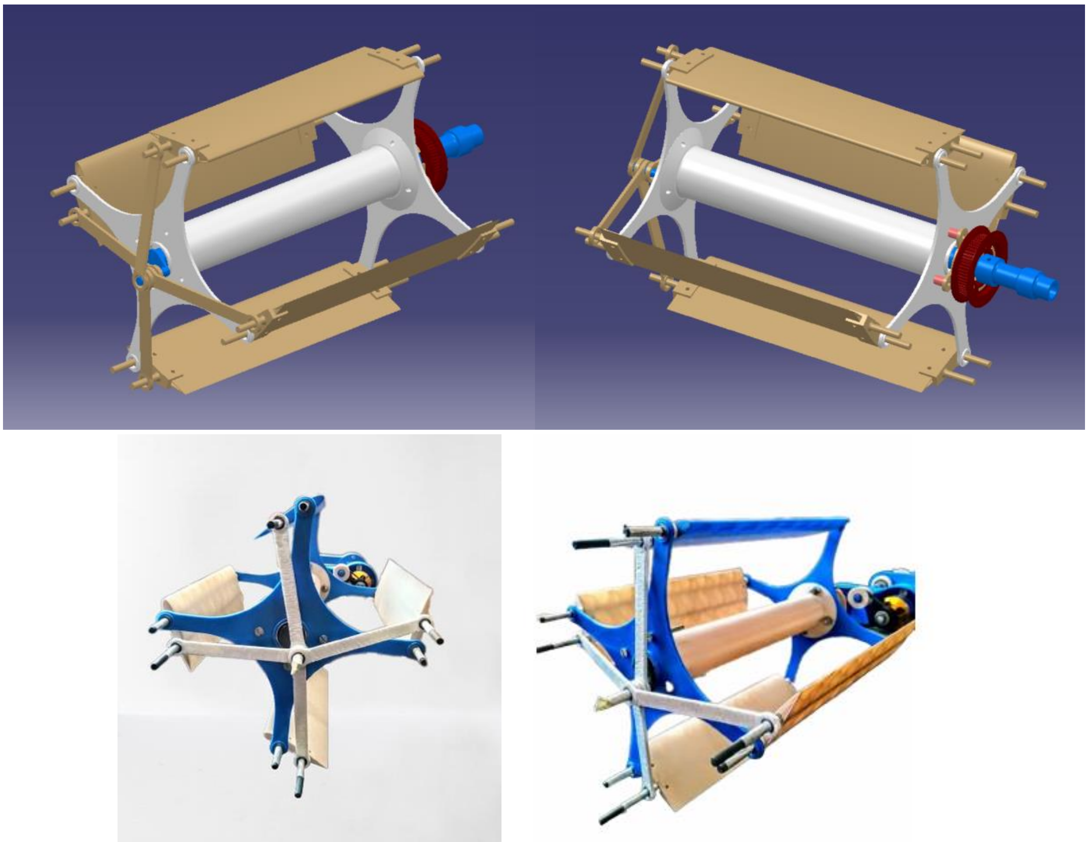
PROJECT TITLE:	DESIGN AND DEVELOPMENT OF CYCLOTOROTOR FOR PARAMETRIC STUDY OF THRUST VECTOR		
DRAWING TITLE:	ASSEMBLY OF CYCLOROTOR		
SCALE	1:3	DRG. SHEET NO.	1/1
THAPATHALI CAMPUS, IOE,TU			
Dimensions are in Metric System			

Results

- The cyclorotor was tested experimentally as well as in CFD simulation. Simulation was carried out in OpenFOAM implementing the PIMPLE algorithm and the SST K-ω turbulence model. The model was run at 1400 RPM and the results were observed. The thrust magnitude varied with the pitching angle (phase angle of eccentricity). The maximum thrust was obtained when the pitching angle was 0^{o} and the thrust was directed in an upwards direction.
- Experimental results also showed variation in thrust magnitude with respect to phase angle of eccentricity and were similar to the simulation result however they differ in pattern. The experimental result showed a curve resembling a sinusoidal curve whereas the simulation curve showed a sinusoidal curve at first and then stabilized later.
- The thrust direction varied at different phase angles of eccentricity. The results showed the thrust direction of the cyclorotor for any phase angle of eccentricity is approximately 180^{o} in phase with the phase angle of eccentricity.

Problems Encountered and Future Scopes

- Fabrication of a cyclorotor is a challenge in itself because of its high number of moving parts.
- The weight reduction of the system is a challenge since most of the parts require strength leading to an increase in the weight of the part.
- The system tends to vibrate with resonance amplitude at certain RPM causing the system to fail.
- The effect of virtual camber and induced downwash shows considerable effect in the cyclorotor performance and hence should be taken into consideration in the design process.



References

1. Benedict, M., Jarugumilli, T., & Chopra, I. (2013). Effect of Rotor Geometry and Blade Kinematics on Cycloidal Rotor Hover Performance. *Journal of the American Helicopter Society*(58), 1-10. doi: doi:10.2514/1.C031461

2. Shrestha, E., Yeo, D., Benedict, M., & Chopra, I. (2017). Development of a Meso-Scale Cycloidal-Rotor Aircraft for Micro Air Vehicle Application. *International Journal of Micro Air Vehicles, 9*(3), 218-231. doi:doi:10.1177/1756829317702048