Design of two-rotored UAV Cyclocopter

Choong Hee Lee[1*], Seung Yong Min[2], Youn Seong Kim[3], Jong Won Lee[4] and Seung Jo Kim[5]
[1,2,3]*School of Mechanical and Aerospace Engineering, Seoul National University*
Seoul 151-742, South Korea
[4,5]*Korea Aerospace Research Institute,*
Daejeon 305-333, South Korea

A cyclocopter or cyclogyro is a type of rotorcraft that is operated by a cycloidal blade system with several blades rotating about a horizontal axis that lies perpendicular to the flight direction [1, 2]. Figure 1 shows a cycloidal blade system with a typical pitch motion of a blade rotating on the orbit. The pitch angle of the blade is in cyclic varying motion. Therefore, the direction of the thrust is roughly the position of maximum pitch angle, or φ=90deg. Owing to the periodic pitch angle variation, a cycloidal blade system has a unique ability that it can change direction and magnitude of the thrust force almost immediately. Moreover, this characteristic enables the system to capable of VTOL maneuver and a forward flight.

The cycloidal blade system was studied at NACA, University of Washington, etc., from 1920's to 1940's [3]. In 1998, Bosch Aerospace carried out a ground test using a six-bladed cycloidal rotor [4]. Recently, University of Maryland developed a MAV cyclocopter and performed flight tests [5]. This year, in October 2012, our laboratory conducted a hovering test using a four-rotored MAV cyclocopter [6]. The rotors of the cyclocopter rotate at constant speed and the blade pitch angles are controlled to generate thrust force. The successful hovering test of the cyclocopter is shown in Figure 2.

This paper introduces a newly designed UAV cyclocopter, which is completely re-designed and currently under manufacturing. The weight is approximately 90kg, substantially larger than the MAV cyclocopter developed in this group. Capacity, maximum power, and type of the engine to be installed are 294cc, 33kW(@8,750rpm), and 4-stroke rotary engine, respectively. However, we will operate the engine at 5,900rpm which results in the output power of 29hp or 21.6kW, and the rotors will rotate at the designed operating speed of 400rpm with the given power. The technical specifications of the cyclocopter are given in Table 1. The sketch is available in Figure 3.

To reduce bending stress of the blades as much as possible, each blade is extended by 150mm and 350mm to inboard and outboard directions, respectively. The total blade length is then 1.5m, increased from the original span length of 1m. There are two U-shaped carbon spars located at front and rear positions inside the blade to endure stress while rotating. This structure is essential since the centrifugal force is huge (180kgf) while the weight of each blade is only 1kg.

To obtain thrust data and the power required to run the system, a set of 2-dimensional computational fluid dynamics (CFD) analyses is carried out. An automatic mesh generation

---

[1] Research assistant, corresponding author
e-mail : chlee@aeroguy.snu.ac.kr
Phone: +82-2-880-7394; Fax: +82-2-872-9262

technique is adopted with appropriate parameter values. For this process, PCL (Patran Command Language) of MSC/PATRAN is applied to generate CFD meshes and to accomplish each analysis simultaneously. CFD analysis is performed using a commercial program, FLUENT. In this work, a 2.66GHz CPU is used for computing the cyclocopter rotor system, and it takes 12 hours to finish each case that has 80,000 cells. Figure 4 shows velocity contours around the rotor system when 4 blades are located at φ=0, 90, 180, and 270 degrees and when maximum pitch angle is 25 degree. Thrust and power curves are given in Figures 5 and 6, for several pitch angles. Although the weight of whole system is 90kg, it is expected that hovering condition happens at around when the maximum pitch is 25 degree and the thrust is 120kgf. Due to several factors missed in the computation such as 3-dimensional effect, induced drag, power train friction, and so on, power requirement is usually higher than the analysis result.

In the new cyclocopter, the control mechanism is modified such that horizontal pitch angle is directly altered instead of controlling phase angle of the cyclic motion. Conventionally, both pitch and phase angles are controlled at the central system with a main control ring to adjust thrust and yawing motion. However, unexpected rolling motions usually occur when controlling yawing axis in the previous approach. Moreover, the system is not axisymmetric since only one linkage is fixed to the main control ring and the other linkages are simply pinned, and the center of the control ring does not coincident with the rotating axis of the blades. Also, in the weight point of view, the system requires a large steel bearing which is heavy.

The proposed control mechanism uses a cam path in which all control linkages are linked to the same connection. Figure 7 shows this mechanism. Therefore, the pitch angle paths for all blades are identical which makes the system axisymmetric, and the heavy bearing is no more needed. This control system is adopted in the newly designed cyclocopter. Manufacturing of this UAV cyclocopter is expected to be completed by February, 2013, and various flying motions will be tested afterward.

Reference

1. Yun, C. Y., “A New Vertical Take-off and Landing Aircraft with Cycloidal Blades System: Cyclocopter,” Ph.D thesis, Seoul National University, 2004.
2. Yun, C.Y., Park, I., Lee, H.Y., Jung, J.S., Hwang, I.S., Kim, S.J. and Jung, S.N., “A New VTOL UAV Cyclocopter with Cycloidal Blades System,” American Helicopter Society 60th annual forum proceeding, Baltimore, MD, June 7 -10, 2004.
3. Wheatley, J.B. “Simplified Aerodynamic Analysis of the Cyclogiro Rotating-wing System,” Technical Notes NACA No.467, August 1933.
4. Gibbens, R.P. and Boschma, J.H. “Construction and testing of a new aircraft cycloidal propeller,” 13th AIAA Lighter-Than-Air Systems Technology conference, Norfolk, VA, June 28-July 1, AIAA No.99-3906, pp.1-9, 1999.
5. Benedict, M., Gupta, R., Chopra, I., “Design, Development and Flight Testing of a Twin-Rotor Cyclocopter Micro Air Vehicle” 67th American Helicopter Society forum Virginia Beach, VA, May 3 -5, 2011.

6. Min, S.Y., Lee, C.H., Seung, M.H., Kim, Y.S., Hur, C.M. and Kim, S.J., “Experiment Study of Quadrotor Cyclocopter” 69th American Helicopter Society forum Phoenix, AZ, May 21-23, 2013.

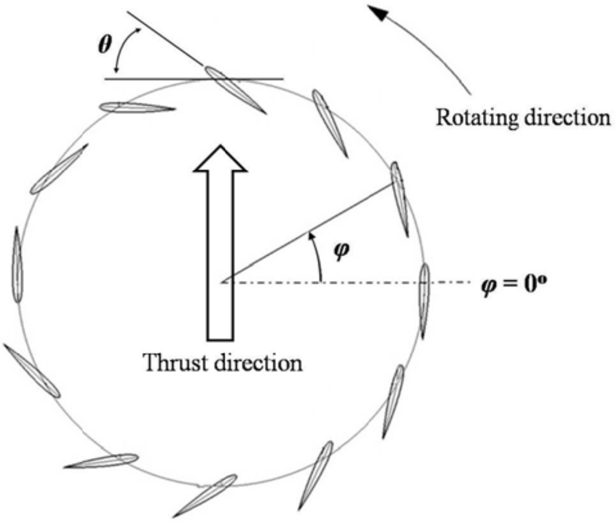

Fig. 1 Cycloidal blade system

Fig. 2 Hovering test of MAV cyclocopter

Table 1 Specifications of UAV cyclocopter

Length include rotors		3,152mm
Height		2,310mm
Width		4,200mm
Weight		90kg
Rotor	Diameter	2,000mm
	Span length	1,500mm
	Airfoil	NACA0018
	RPM	400RPM
	Pitch angle	0~35˚
Engine	Type	4-stroke single rotor rotary engine
	Power	33kW at 8750rpm
	Chamber Vol.	294cc

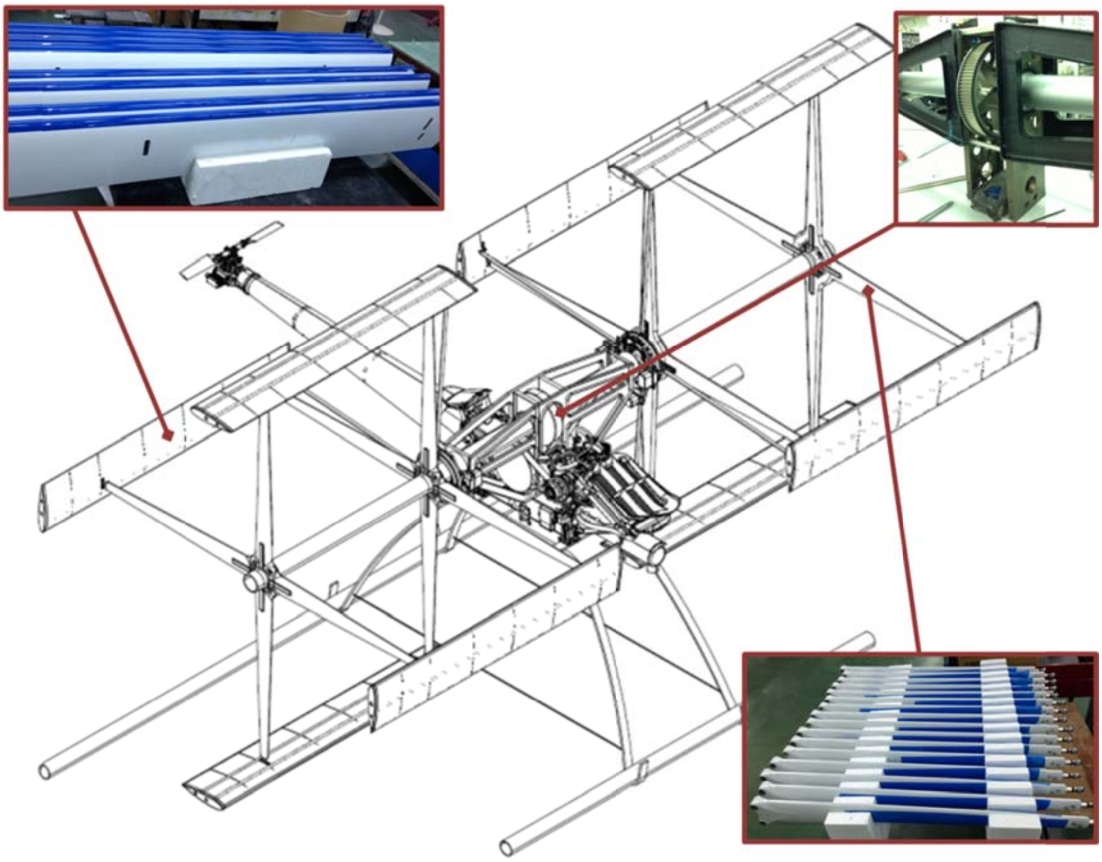

Fig. 3 Sketch of UAV Cyclocopter

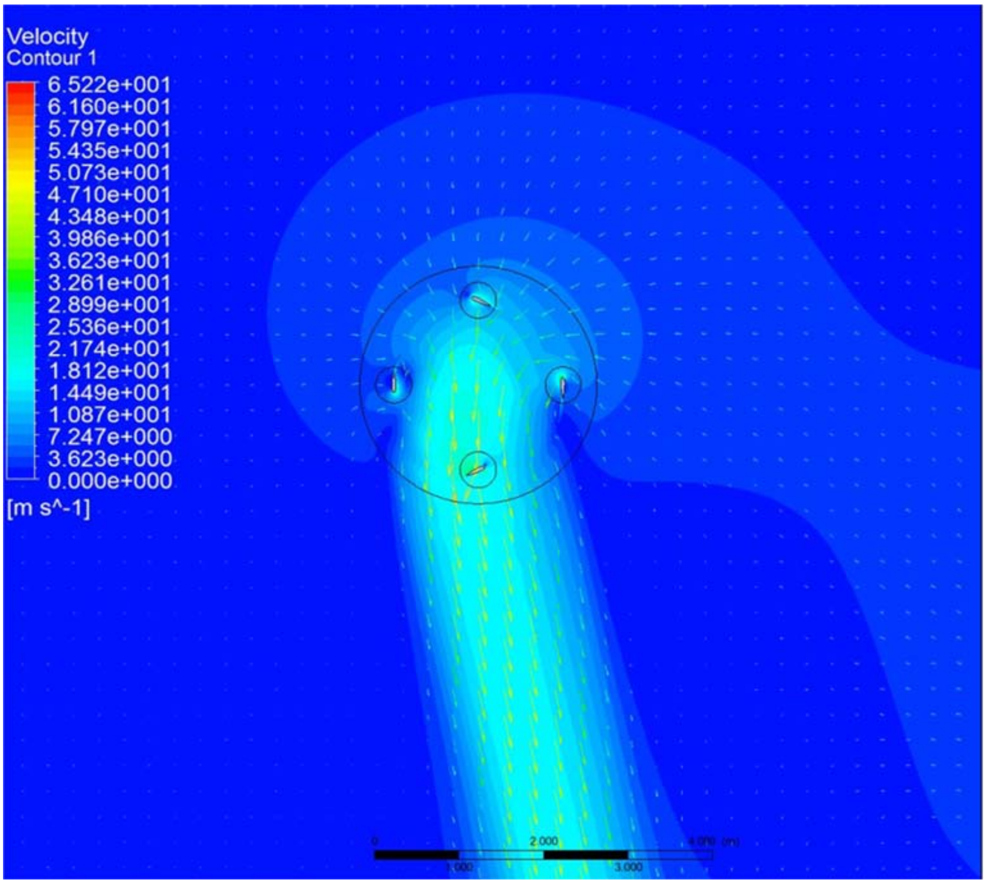

Fig. 4 Velocity distribution from a 2D CFD calculation

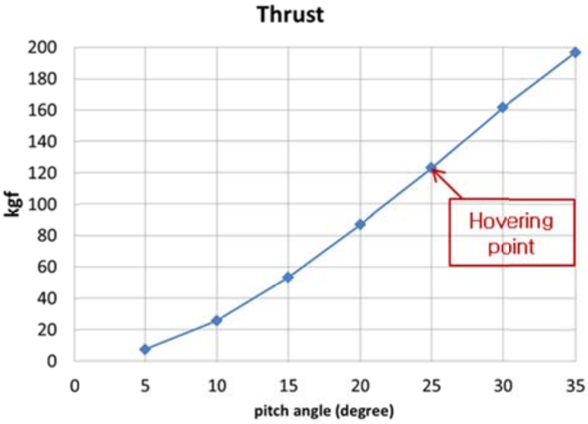

Fig. 5 Thrust vs. pitch angle

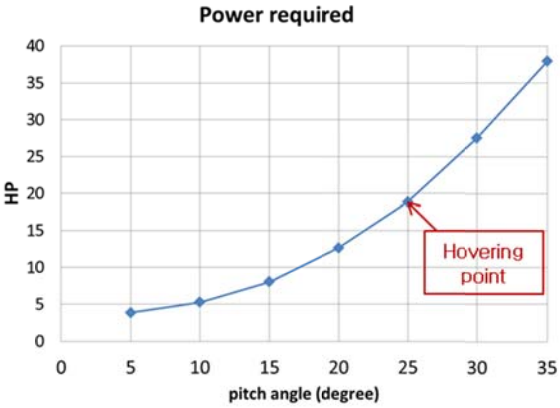

Fig. 6 Power required vs. pitch angle

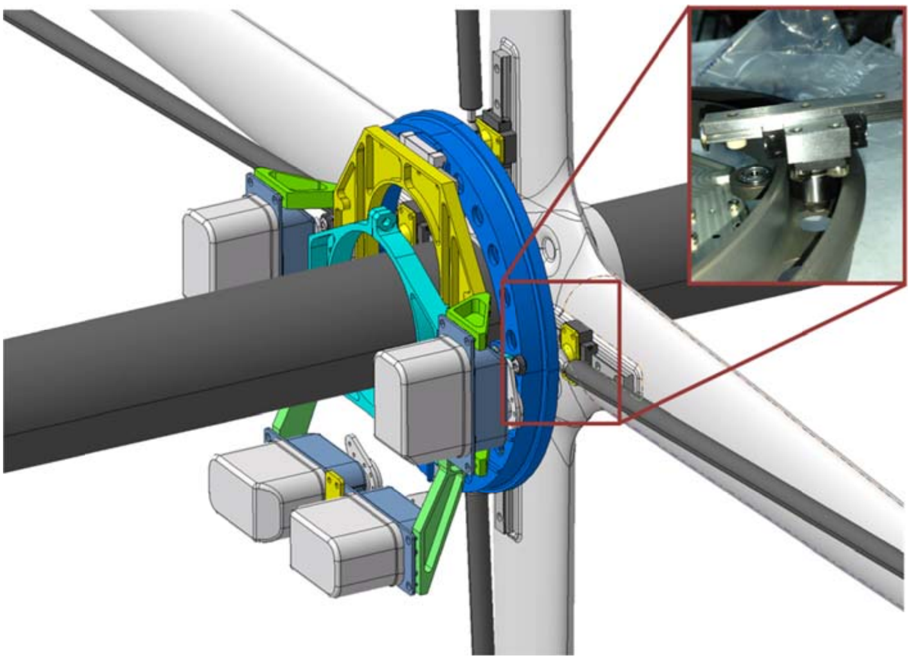

Fig. 7 Control mechanism