# Design of the pitching mechanism used in a cyclocopter

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***Abstract:*** A cyclocopter is rotary vehicle configuration that uses cycloidal rotors to generate lift and perform other maneuvers. Cycloidal rotors are rotors that rotate about a horizontal axis which when connected using a pitching mechanism are able to perform different maneuvers within its flight envelope. Thus, an efficient pitching mechanism serves as a vital component in the design of a cyclocopter. The main aim of this study is to publish the design methodology that is used in the design of a cyclocopter pitching mechanism using a CAD model. This study can serve as a general reference guide for future cyclocopter designs.

## I. INTRODUCTION

A cyclocopter is a type of rotary vehicle configuration that uses cycloidal rotors (see figure 1) to generate lift. It was first conceptualized in 1927 by John Edward Caldwell. Multiple attempts were made by different individuals to realize this concept. One of them was by a German named Adolf Rohrbach who designed a full sized VTOL aircraft in 1933. Another example was by Rahn Aircraft in 1933 which used two much larger chord wings instead of a multi-blade wheel driven by a 240 hp supercharged Wright Whirlwind. In 1935 NACA carried out a series of wind tunnel experiments on the cyclocopter concept, and found that the power required to turn the wheels was much higher than expected. As a result, such a concept was deemed unfeasible.

It is only in the recent past that significant progress has been made in the development of a cyclocopter. In 2010, a team from the University of Maryland designed and developed the world's first successful cyclocopter. In 2017 an Austrian company called D-Dalus released plans for a futuristic cyclocopter design and in 2018 the world's smallest cyclocopter was designed.

***Abbreviations and acronyms used in this paper***

CAD – Computer Aided Design
NACA – National Advisory Committee for Aeronautics
UIUC – University of Illinois at Urbana-Champaign
STEP – Standard for the Exchange of Product Data
$L_1$ –mounting arm length
$L_2$ – distance between the mounting and pitching arm
$L_3$ – pitching arm length
$L_4$ – offset length
R – axis of rotation of rotary shaft
O – axis of rotation of pitching shaft
AOA – Angle of attack

## II. METHODOLOGY

The main objective of this paper is to explain the design of the pitching mechanism of a CAD model.
The methodology section outlines the plan and method followed during the study. The details are as follows:

1. Literature Survey:
   The first step in conducting this study was to research about all the available literature on the topic.
2. Understanding the operation of the cyclocopter:
   A cyclocopter consists of cycloidal rotors spinning about a given axis. The rotating rotors generate lift to lift the vehicle off the ground. Two images depicting a cyclocopter in motion are shown below.

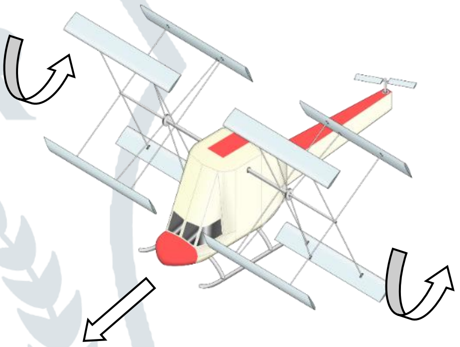

Fig. 1 Artist's impression of a working cyclocopter

3. Understanding the working of the mechanism:
   The challenging part in developing a successful cyclocopter is in developing a successful pitching mechanism.

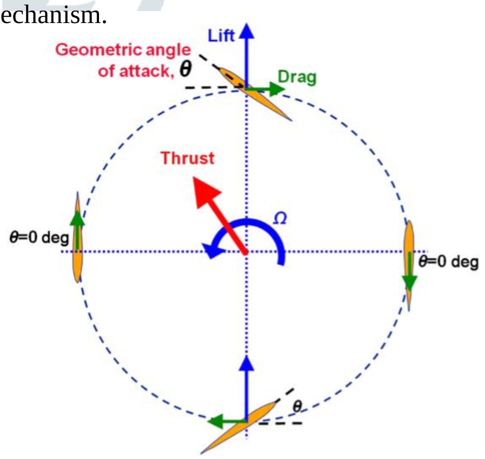

Fig. 2 Blade pitching kinematics [2]

Although studies have been caried out different researches, most studies have not shared much information on the pitching mechanism itself.

Moble Benedict[1] published a useful schematic image of the cyclocopter pitching mechanism in his Ph.D. dissertation. This figure is shown below.

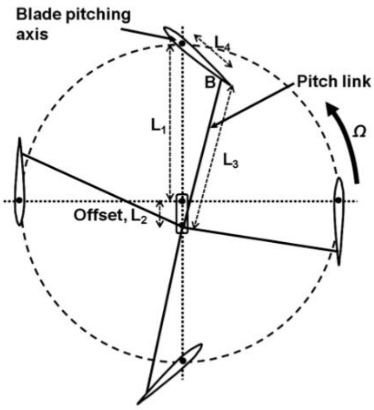

Fig. 3 Schematic of the blade pitching mechanism[1]

Note, the angle of the blades can be changed by changing the offset length $L_2$[1]. Although, this diagram is a wonderful schematic to understand the working of the cyclocopter, it does not give much information on how the blades and the shafts are attached to each other.

4. Development of the CAD model:

The final step in this study was the development of a CAD model. To design the CAD model, Solid Edge ST10 Academic Edition software was used. It is a robust design software with simple tools and widely available documentation. The steps followed in the design phase are highlighted below:

*a)* Selecting an appropriate airfoil design:

The airfoil chosen for this project is a symmetric NACA 0012 airfoil. The co-ordinates to plot the NACA 0012 are obtained from UIUC Airfoil Data Site. The website stores a data-base of numerous airfoil co-ordinates conforming to NACA and/or other standards. The values for the airfoil co-ordinates obtained are extrapolated to the correct scale. For this project a NACA 0012 airfoil with chord length of 30mm and width of 100mm is selected. The mounting rods and pitching rods are at 25% and 50% of distance from the leading edge respectively[4].

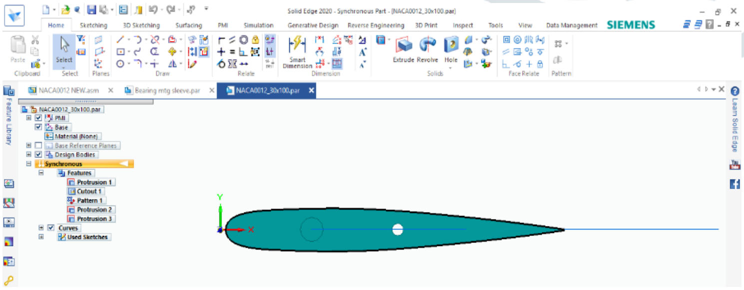

Fig. 4 A cross-sectional view of the completed airfoil

*b)* Development of the rotary and pitching shafts:

The rotary and pitching shafts need to perform rotary and pitching operations independently without interfering in the operation of the other. The position of the shafts also needs to be decided i.e., mounting the shafts co-axially or along different axes. Necessary support in terms of bearings etc. needs to be provided.

*c)* Selection of correct bearing size and type:

Numerous bearing types like deep grove ball bearings, needle bearings, cylindrical bearings etc., are available. Selection of bearings must be done in such a way so as to fit in the available space whilst providing adequate support.

*d)* Design of other components:

The pitching mechanism of a cyclocopter consists of other structures like mounting arm, pitching arm(s) etc. All these components need to be designed considering factors like max. pitching angle, rotational trajectory etc.

*e)* Assembly of the components:

The final step in the development of the CAD model is the assembly of the individual members with correct assembly conditions.

## III. RESULTS AND DISCUSSION

### 3.1 Development of the rotary and pitching shaft

The rotary and pitching shaft are developed in a manner so as to perform independently without affecting the function of the other. The main hindrance in the development of the shafts is the limited availability of space to create two independent shafts. To overcome this issue, two concentric shafts were developed. These two shafts can now be mounted securely over each other by utilizing needle bearings.

### 3.1.1 Development of the rotary shaft

The rotary shaft is developed to connect the mounting arms which connect to the cyclocopter blades with the input drive. Butting surfaces are provided to butt the mounting arms onto the rotary shaft. Grooves are provided to insert a circlip to secure the mounting arms.

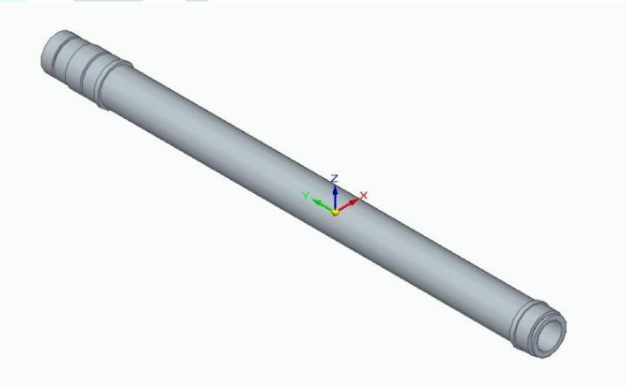

Fig. 5 A screenshot of the rotary shaft

### 3.1.2 Development of the pitching shaft

A screenshot of the pitching shaft is attached below. The pitching shaft consists of two axes which have been eccentrically shifted by an offset equal to $L_2$.

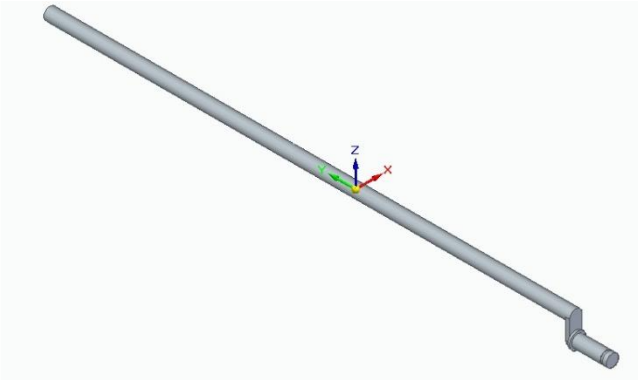

Fig. 6 A screenshot of the pitching shaft

### 3.2 Selection of the bearings

After considering the space constraints and the other parameters, needle bearings were selected as the preferred choice for this application. The CAD model for the bearings were obtained as STEP(.stp) file from a reputed bearing manufacturer’s online catalogue. Some of the properties of the bearing selected are shown in the table below.

| | |
|---|---|
| Basic dynamic load rating | 1.51 kN |
| Basic static load rating | 1.34 kN |
| Reference speed | 40000 r/min |
| Limiting speed | 45000 r/min |

Table. 1 Major properties of the bearing(s) selected

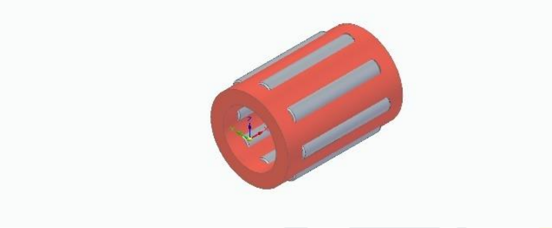

Fig 7. A screenshot of the bearings used in the model

### 3.3 Assembly of components

#### 3.3.1 Mounting arrangement between the rotary shaft and pitching shaft

The shafts are mounted coaxially with the help of needle bearings (shown in green). The bearings for this application have been selected considering factors like dynamic loading and max RPM. The bearings are used to locate one shaft inside the other. More importantly, the bearings provide a way to independently control either shaft. Note, the purple coloured shaft is the pitching shaft and the silvered coloured shaft is the rotary shaft.

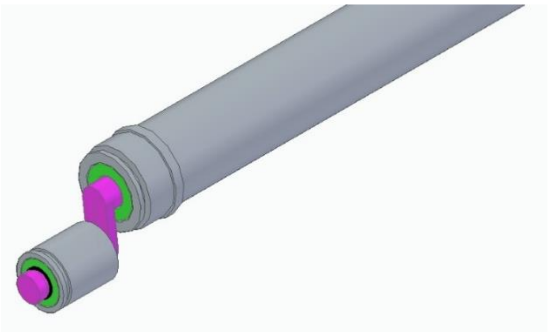

Fig. 8 A screenshot of the assembly of the rotary and pitching shaft.

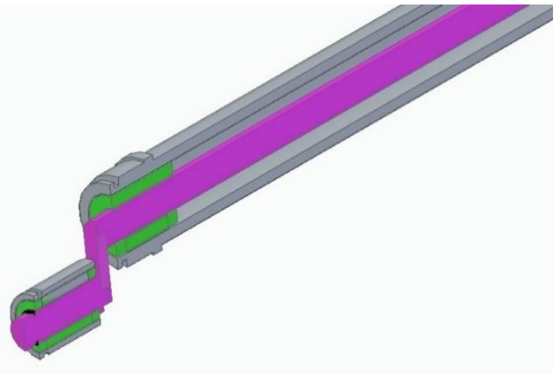

Fig. 9 A cut-section of the assembled rotary and pitching shaft

#### 3.3.2 Attachment of the pitching arm and the mounting arm

The mounting arm (shown in yellow) and the pitching arms (shown in brown) can be fitted onto the respective shafts. The pitching arms are connected to the bearing B1 via a coupling. The pitching arms and the mounting arms once fitted onto the respective bearings can be secured in place using circlips.

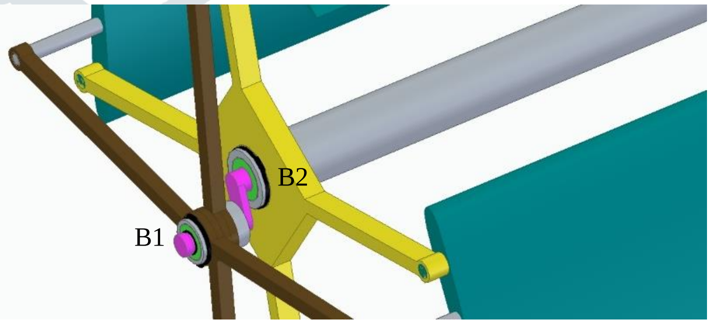

Fig. 10 Close-up screenshot of the assembly

#### 3.3.3 Final assembly of the cyclocopter

After all the individual components of the cyclocopter have been assembled a final assembly is created. A screenshot of the final assembly is shown in figures 11 & 12. The individual parts have been colour-coded to help with easy identification.

Explanation of color-coded components:

1. Teal-NACA 0012 airfoil(s)
2. Yellow-Mounting arm(s)
3. Brown-Pitching arm(s)
4. Silver-Rotating shaft

5. Purple-Pitching shaft
6. White-Input gear assembly for the rotating shaft*
7. Red-Input drive for the rotating shaft*
8. Blue-Input drive for the pitching shaft*
9. Green- Needle Bearings

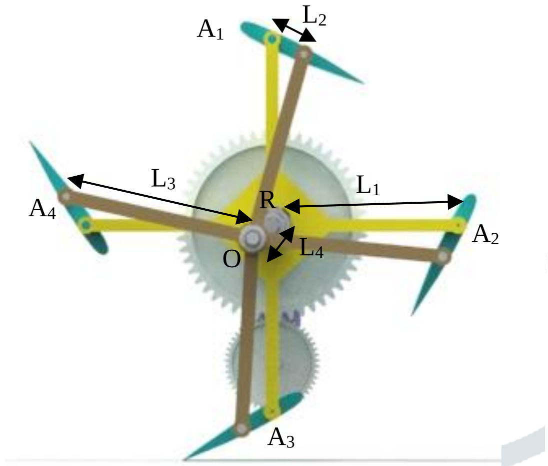

Fig. 11 A front view of the cyclocopter assembly

The four values shown in the above figures are of utmost importance in the development of a pitching mechanism of the cyclocopter. The definition of the four terms and the values set in this project are given below:

1. $L_1$=mounting arm length, 40mm
2. $L_2$=distance between the mounting arm and the pitching arm, 7.5mm
3. $L_3$=pitching arm length, 41mm
4. $L_4$=offset length, 5mm

The values defined above set the range of geometric angle of attack of the airfoil from -50° to 37°. An understanding of how the geometric angle of attack of the cyclocopter changes during a rotation of the pitching shaft is shown in the section 3.4.

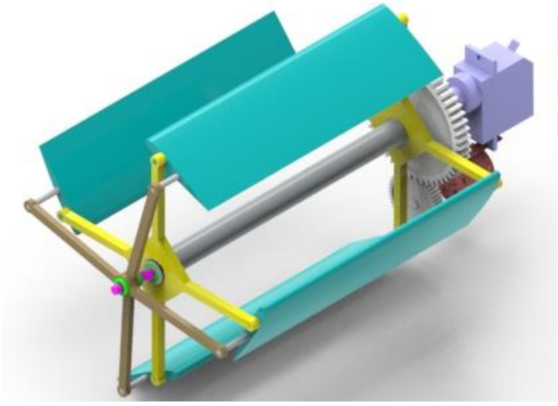

Fig. 12 3D view of the cyclocopter assembly

Note, the components marked with * are not in the scope of this paper. They are shown for visualization purposes only.

### 3.4 Geometric AOA at different positions

It is important to understand how the airfoils behave with the constraints mentioned in section 3.3.3. In this section the trajectory of the cyclocopter blades have been shown for better understanding of the working of the cyclocopter.

The path in blue shows the trajectory of the pitching arm and the path in black shows the trajectory of the mounting arm. The direction of rotation is in the counter-clockwise direction.

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### 3.4.1 When top airfoil is at 0° AOA

Due to the mechanism, there are two ways of achieving 0° AOA in the cyclocopter i.e., either by pitching the offset shaft to the left or to the right. A schematic diagram of the orientation of the shaft to the left of the cyclocopter and the positions of the various airfoil blades are shown in figure 13 and a corresponding screenshot of the arrangement is shown in figure 14.

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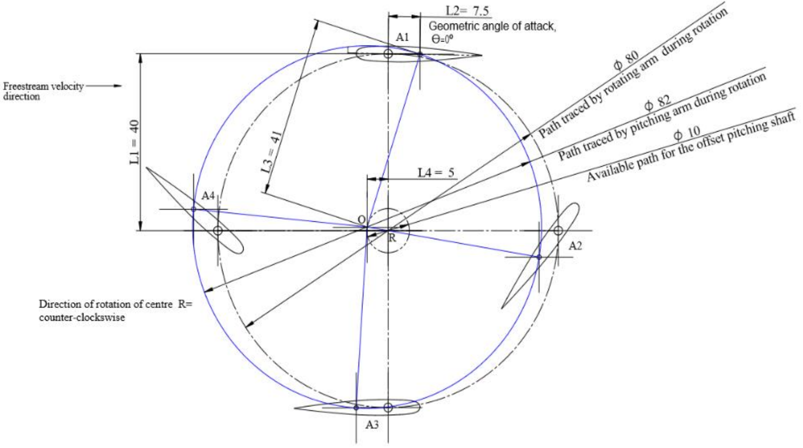

Fig. 13 Schematic diagram of the cyclocopter links with the pitching shaft rotated to the left

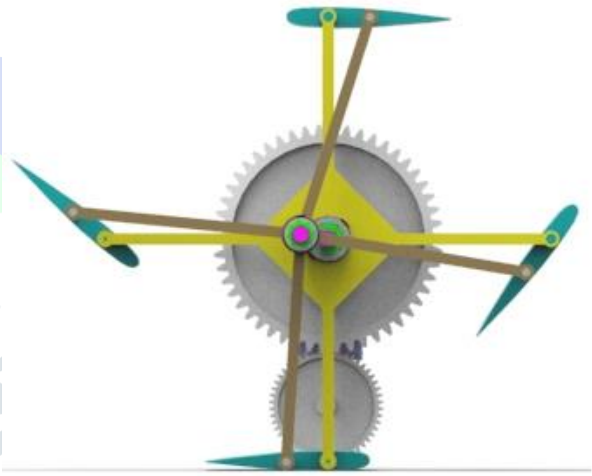

Fig. 14 Position of the airfoils with the pitching shaft rotated to the left

In a similar manner 0° AOA in the cyclocopter can also be achieved by rotating the offset shaft to the right. A schematic diagram of the orientation of the shaft to the right and the corresponding positions of the airfoils are shown in figures 15 and 16 respectively.

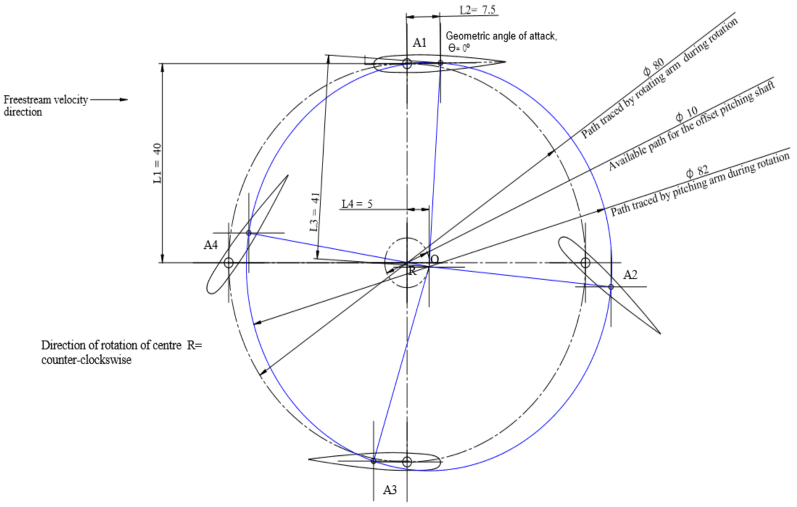

Fig. 15 Schematic diagram of the cyclocopter links with the pitching shaft rotated to the right

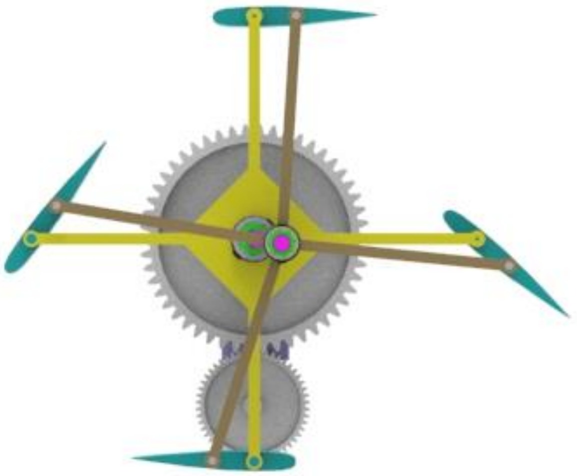

Fig 16. Position of the airfoils with the pitching shaft rotated to the right

### 3.4.2 When top airfoil is at max positive AOA

The maximum positive AOA can be achieved by rotating the pitching shaft to the central position on the bottom side of the rotating shaft.

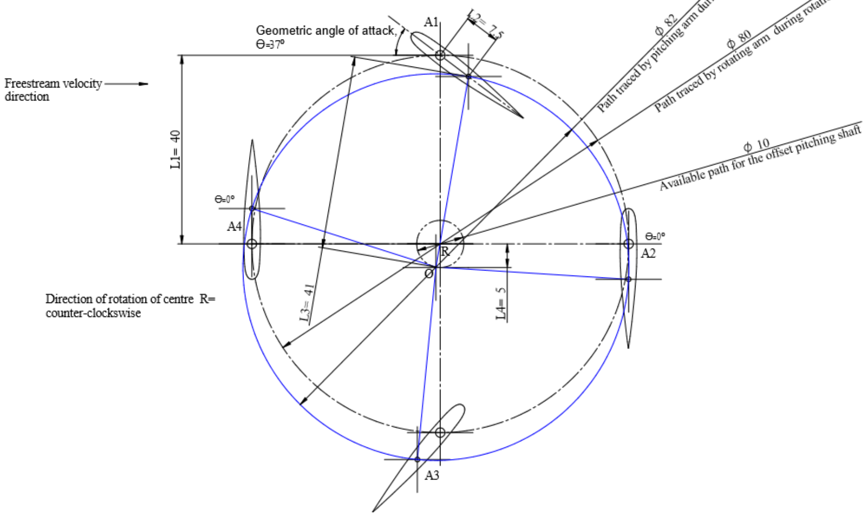

Fig. 17 Schematic diagram of the cyclocopter links with the pitching shaft rotated to the bottom

Note, at this point the airfoils A2 & A4 will be perpendicular to the incoming free steam.

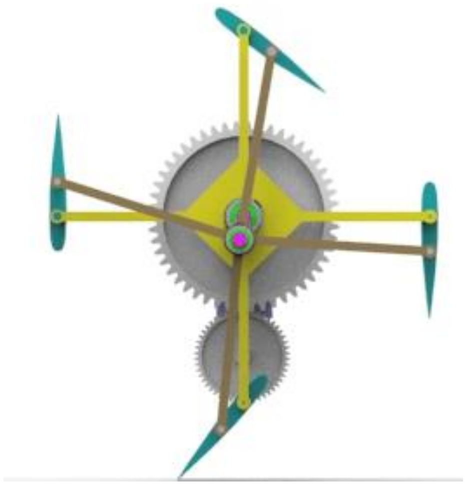

Fig 18. Position of the airfoils with the pitching shaft rotated to the bottom

### 3.4.3 When top airfoil is at max negative AOA

The maximum negative AOA can be achieved by rotating the pitching shaft to the central position on the top side of the rotating shaft.

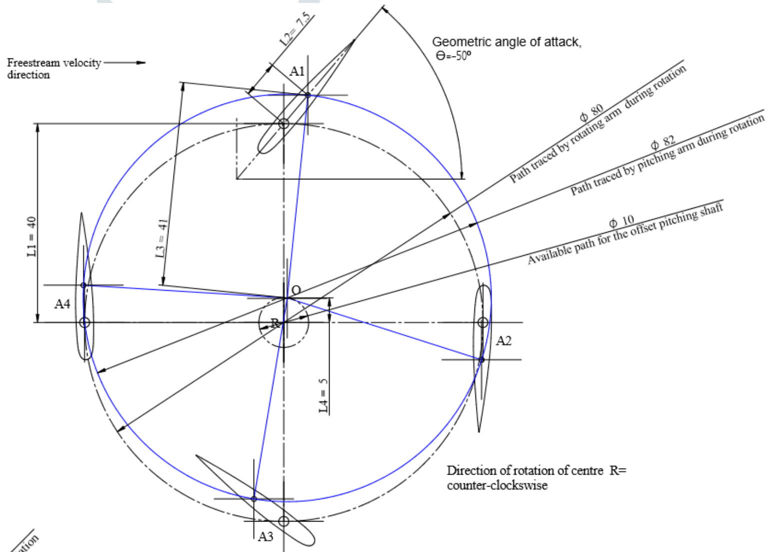

Fig. 19 Schematic diagram of the cyclocopter links with the pitching shaft rotated to the top

Note, at this point the airfoils A2 & A4 will be perpendicular to the incoming free steam

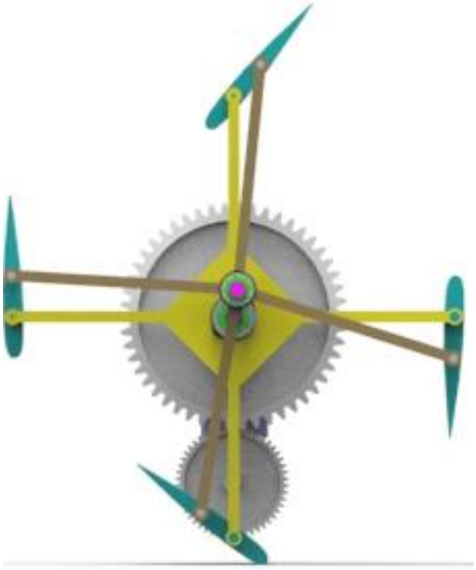

Fig. 20 Position of the airfoils with the pitching shaft rotated to the top

## IV. CONCLUSION

The objective of this study was to share the design methodology used in the design of the pitching mechanism of the cyclocopter. The cyclocopter dimensions viz., $L_1$, $L_2$, $L_3$, $L_4$ chosen for this study were for a Micro-Aerial Vehicle (MAV) size configuration. The construction of a similar mechanism can be used for studies on future models of MAV's or other rotary aircraft configurations. More importantly, the methodology highlighted here can be used as a general reference to design subsequent future models for theoretical and experimental studies.

## V. ACKNOWLEDGMENT

I would like to thank Dr. S. K. Maharana for his constructive feedback during the initial stages of this project's conceptualization. I also wish to acknowledge the efforts of Abhilash Bhattacharya, Dipanshu Tiwari, Karunesh Parakh and Prof. Roohi. Finally, I would also like to thank Sudesh Kumar who provided some crucial inputs to the project.

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