Flapping Wing Air Vehicle using Whitworth Quick Return Mechanism

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Introduction and Objective of Proposed Work

In this paper, we will focus on the mechanism to be used for the design of a flapping wing micro air vehicle (MAV) and see how it can be much more efficient than simple rotor based designed air vehicles. Here we use Whitworth Quick Return Mechanism, an inversion of single slider crank mechanism, to acquire the desired result. It is set such that the up-stroke of the wing is the forward stroke and the down-stroke is the return stroke (quicker) which creates resultant downward thrust thus generating an upward force which helps in lifting of the vehicle.

The idea of 'flapping wings' is inspired from nature itself, which is observed in the motion of birds. Flapping wings may offer improved efficiency, better maneuverability, and reduced noise compared with the rotary-driven air vehicles. The resemblance to a real bird can also make it unrecognizable and make it handy for secret military intelligence missions. The drones built, if fitted with camera can also be useful in areas like security surveillance.

Background Theory

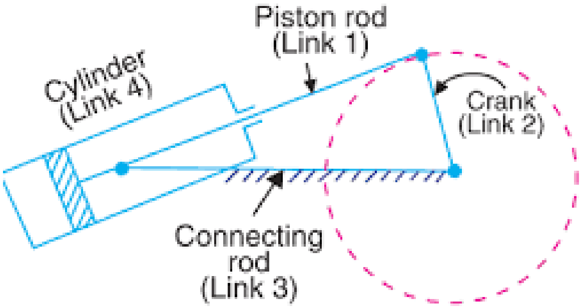
Definitions:

Kinematic Link: Each part of a machine, which moves relative to some other part, is known as a kinematic link (or simply link) or element.

Kinematic Chain: When the kinematic pairs are coupled in such a way that the last link is joined to the first link to transmit definite motion (i.e. completely or successfully constrained motion), it is called a kinematic chain.

Mechanism: The term mechanism is applied to the combination of geometrical bodies which constitute a machine or part of a machine. A mechanism may therefore be defined as a combination of rigid or resistant bodies, formed and connected so that they move with definite relative motions with respect to one another.

Single Slider Crank Chain



The Single Slider Crank Chain is a Four-Bar Mechanism. As the name single slider crank chain indicates it consists of only one sliding pair (ram) and three turning pairs (connecting rod, crank, and frame). So, the main aim of the single slider crank chain mechanism is to convert the rotary motion (with the help of turning pairs) into sliding motion or vice versa.

Whitworth Quick Return Motion Mechanism:

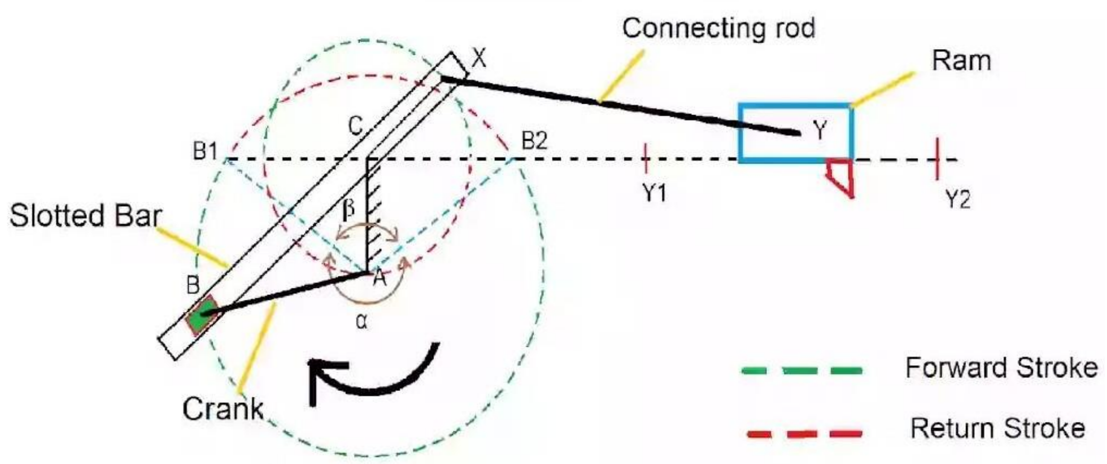
Whitworth quick return mechanism is the inversion of a single slider crank chain. It consists of three turning pairs & one sliding pair. The Whitworth mechanism is all about converting rotary motion (or turning motion) into the sliding motion (or to and fro motion). As the name, Quick Return indicates that the return stroke of the mechanism is faster (or quicker) than the forward stroke.

Parts:

The Whitworth quick return mechanism is the inversion of singer slider crank chain then Whitworth mechanism does consist of similar construction and working parts but may vary a few parts in it. The typical Whitworth quick return mechanism consists of four links:

(a) Ram: The ram is the one and only sliding pair in the Whitworth mechanism and slides over fixed guideways to perform the operations.
(b) Connecting Rod: It is a turning pair in the Whitworth mechanism. Connecting Rod is a connecter of ram and crank which even helps in conversion of rotary motion to sliding motion
(c) Crank: Crank is a type of turning pair and it is a rotary type part in the Whitworth mechanism.
(d) Frame: The whole parts and mechanism are fixed to the frame. It is solid pair.

Working:



Whitworth quick return mechanism working consists of two strokes:-

1] FORWARD STROKE:

For forward stroke, the crank AB is moves from B2 to B1 in a clockwise direction.

At the same time point, X on connecting rod moves from B1 to B2 in a clockwise direction & the ram move in forward direction from Y1 to Y2.

For forward stroke crank AB has to complete angle α.

[The movement of forward stroke is shown in the figure with a green dotted line]

2] RETURN STROKE:

For return stroke, the crank AB is move from B1 to B2 in a clockwise direction.

At the same time, the point X on connecting rod moves from B2 to B1 in a clockwise direction & the ram moves in a reversed direction from Y2 to Y1.

For reversed stroke, crank AB has to complete angle β.

[The movement of return stroke is shown in the figure by red dotted line]

RELATION BETWEEN TIME TAKEN FOR FORWARD AND REVERSE STROKE:

1] When the crank moves from B2 to B1 in a clockwise manner, the ram moves from Y1 to Y2 (forward). It means that, **Time for forward stroke of ram = Time to complete angle α by crank**

2] When the crank moves from B1 to B2 in a clockwise direction, the ram moves from Y2 to Y1 (return). It means that, **Time for return stroke of ram = Time to complete angle β by crank**

3] From the figure as we know $\beta<\alpha$. It means that the ram moves quicker in return stroke & it takes much time for forward stroke.

The ratio of time for forward stroke & return stroke is given by,

TIME FOR FORWARD STROKE/TIME FOR RETURN STROKE=α/β or $\alpha/360-\alpha$

Advantages of Whitworth Quick Return Mechanism:

The Advantages of Whitworth Quick Return Mechanism are

- Due to the forward slow movement of the Whitworth mechanism, the work piece gets good finishing.
- The time of machining is less in the Whitworth mechanism.
- Whitworth Quick Return mechanism is simple in construction and easy to operate.

Applications of Whitworth Quick Return Mechanism:

General applications of Whitworth quick return mechanism include:

- Shaping Machines
- Slotting Machines

Literature Review

1. Recent progress in flapping wing aerodynamics and aero-elasticity

Author(s): W Shyy, H Aono, P Trizila, CK Kang, CES Cesnik (Department of Aerospace Engineering, University of Michigan); H Liu (Graduate School of Engineering, Chiba University)

Publishing Year: February 2010

Link: https://www.sciencedirect.com/science/article/abs/pii/S0376042110000023

Micro air vehicles (MAVs) have the potential to revolutionize our sensing and information gathering capabilities in areas such as environmental monitoring and homeland security. Flapping wings with suitable wing kinematics, wing shapes, and flexible structures can enhance lift as well as thrust by exploiting large-scale vortical flow structures under various conditions. However, the scaling invariance of both fluid dynamics and structural dynamics as the size changes is fundamentally difficult. This review focuses on assessing the recent progress in flapping wing aerodynamics and aero-elasticity. It is realized that a variation of the Reynolds number (wing sizing, flapping frequency, etc.) leads to a change in the leading edge vortex (LEV) and span wise flow structures, which impacts the aerodynamic force generation. While in classical stationary wing theory, the tip vortices (TiVs) are seen as wasted energy, in flapping flight, they can interact with the LEV to enhance lift without increasing the power requirements. Surrogate modeling techniques can assess the aerodynamic outcomes between two- and three-dimensional wings. The combined effect of the TiVs, the LEV, and jet can improve the aerodynamics of a flapping wing. Regarding aero-elasticity, chord wise flexibility in the forward flight can substantially adjust the projected area normal to the flight trajectory via shape deformation, hence redistributing thrust and lift. Span wise flexibility in the forward flight creates shape deformation from the wing root to the wing tip resulting in varied phase shift and effective angle of attack distribution along the wing span. Numerous open issues in flapping wing aerodynamics are highlighted.

2. A Review of Flapping Wing MAV Modelling

Author(s): Victor M Mwongera (University of Bristol)

Publishing Year: April 2015

Link: https://www.researchgate.net/publication/280575013_A_Review_of_Flapping_Wing_MAV_Modelling

This paper gives a comprehensive introduction to the world of flapping flight in both nature and modelling. The unique aspects of this flight regime are demonstrated in the aerodynamics and the control approach seen. The studies focus more on larger insect flight; the design target of the flapping wing MAV being studied. The paper also presents work done so far to model these effects in order to examine the feasibility and challenges of creating a flapping wing MAV. The nonlinear effects explored in both the aerodynamic and kinematic properties of flapping wing flyers indicate that, in order to accurately study the stability behaviour of this flight regime, it is necessary to create a model that captures enough of these effects; in particular, the nonlinear aerodynamics, the periodic forcing and the resulting periodic inertial effects from the flapping wings. The paper also explores the different assumptions that have been used in the literature to develop flapping wing models. The paper demonstrates that the various stability analyses in the literature, primarily performed on insects, are for specific flight conditions. The inherent behaviour and resulting knowledge of flapping flight is therefore from multiple studies and as a result incomplete. Consequentially, there is a need for a comprehensive approach to the study of the stability characteristics of a flapping wing MAV in order to gain a deeper understanding across its potential operating envelope.

3. Flapping wing micro-aerial-vehicle: Kinematics, membranes, and flapping mechanisms of ornithopter and insect flight

Author(s): MFB Abas, ASM Rafi, KAB Ahmad (Department of Aerospace Engineering, Universiti Putra Malaysia); HB Yusoff (Faculty of Mechanical Engineering, Universiti Teknologi MARA Pulau Pinang)

Publishing Year: August 2015

Link: https://www.sciencedirect.com/science/article/pii/S1000936116300978

The objective of this research paper is to provide essential information on ornithopter- and insect-type flapping wing kinematics and membrane wing structures and their contribution towards generated lift, thrust, and drag forces. The contents of this review are arranged as follows: first, an introduction on bio-mimicry system is presented and then mimicking flying animals is discussed, followed by summarized ornithopter and insect flapping wing kinematics and membrane wing structures, and the contribution of both towards generated lift, thrust, and drag forces. Research approaches, flapping wing mechanisms, flow mechanisms, other important aspects, critical issues, and recommendations are discussed afterwards. General guidelines have been presented as well to aid in narrowing the scope of research and to determine specific approaches. As a conclusion from the guidelines, a possible scope for future MAV development has been determined. Issues of which previous researchers have come upon have been listed for future reference and await further improvements. All in all, this review paper provides a new set of references which can be beneficial for future researches.

4. Effect of clap-and-fling mechanism on force generation in flapping wing micro aerial vehicles

Author(s): SS Jadhav (National University of Singapore); KB Lua (National Chiao Tung University); WB Tay

Publishing Year: February, 2019

Link: https://iopscience.iop.org/article/10.1088/1748-3190/ab0477/meta

The clap-and-fling effect which is observed in a number of insects, serves as a lift-enhancing mechanism for bio-inspired flapping wing micro aerial vehicles (MAV). In the comprehensive literature survey, we observe that the effect manifests differently in insects and contemporary MAVs; insects have active control over the angle of attack and stroke plane of the wing, whereas a number of kinematic parameters of an MAV's flexible wings are determined passively. Although there is consensus that flinging motion significantly enhances aerodynamic lift, the effect of clapping motion has not been well-studied. In this experiment, we find quantification of the contribution of clapping motion using force measurement and particle image velocimetry which bridges the gap. No significant enhancement in lift was observed due to clapping motion, because the momentum jet was too weak. However, the kinematics and flow conditions in the study were notably different from those in the previous studies on insect models. The wings of the MAV are flexible, and deform passively. Hence, the clapping of the trailing edges, and the appearance of a trailing edge momentum jet, was delayed and significantly suppressed. Using force measurement and CFD simulations, it is also observed that the lesser the distance between the leading edges of the wings at the end of clap, the higher is the lift due to the subsequent fling.

5. A Review of Design and Fabrication of the Bionic Flapping Wing Micro Air Vehicles

Author(s): C Chen, T Zhang (College of Instrumentation & Electrical Engineering, Jilin University, China)

Publishing Year: February 2019

Link: https://www.mdpi.com/2072-666X/10/2/144

This study reviews the state-of-the-art FWMAVs of various research institutes driven by electrical motor, mechanical transmission structure and “artificial muscle” material and then elaborates on the aerodynamic mechanism of micro-winged birds and insects. The paper summarizes and discusses the system level of FWMAVs with a focus on state-of-the-art FWMAVs, aerodynamic mechanisms, transmission mechanisms and power electronic interfaces. First, various FWMAVs driven by electrical motor, mechanical transmission structure and “artificial muscles” material and investigated by research institutes are presented in detail. The unique aerodynamic modes of bird-mimetic flapping wing and insect-mimetic flapping wing aerial vehicles, which are unlike those of fixed-wing and rotary-wing aerial vehicles, are likewise elaborated. The selection and design of the mechanical transmission are considered based on the stringent requirement of physical and electrical performance in micrometer- to centimeter-scale level. Finally, power electronic topologies suitable for driving “artificial muscle” materials used in FWMAVs are stated. These results present some possible solutions for the creation of insect-sized FWMAVs and a substantial step toward the realization of flying micro robots.

Further size and weight reductions of FWMAVs are important issues for the future. MEMS technologies can be used to provide devices, such as lighter, smaller and less power consuming components than the current state of-the-art ones. Nanotechnology could play an important role also in aerodynamic improvements. FWMAVs will most likely be equipped with GPS and radar systems. Infrared and/or high-definition cameras could be included. Furthermore, trends could also include the development of sophisticated software that will enable the operation of future ultra-small FWMAVs. Finally, with the improvements of artificial intelligence, some of them will have decision-making capabilities, opening the way to completely new mission profiles.

6. Comparison Study on Flapping Mechanisms of Flapping Wing Micro Air Vehicle Characterized on Hovering Flight

Author(s): Y Nan (Glasgow Caledonian University); L Chen (Newcastle University); D McGlinchey (Glasgow Caledonian University)

Publishing Year: March, 2019

Link: https://www.researchgate.net/publication/333890842_Comparison_Study_on_Flapping_Mechanisms_of_Flapping_Wing_Micro_Air_Vehicle_Characterized_on_Hovering_Flight

Flapping mechanism, as one of important components of a flapping wing Micro Air Vehicle (MAV), is directly related to the flapping motion, and further influences on flight performance when flying. This paper deals with designing an efficient flapping mechanism. In this paper, flapping mechanisms of three existing successful flapping wing MAVs with hovering and actively stable flight performances are comparably and analytically studied. Via kinematic analysis, the results indicate that the designed flapping mechanism of ASL hummingbird-like robot (ASL-Colibri) seems to be better than the other two. However, others two can still have stable flight, which means that no perfect design on flapping mechanism may be compensated through an active control so as to make them stable flying.

7. Wing Design, Fabrication, and Analysis for an X-Wing Flapping-Wing Micro Air Vehicle

Author(s): BH Cheaw, HW Ho, AB Elmi (Universiti Sains Malaysia)

Publishing Year: August 2019

Link:
https://www.researchgate.net/publication/335314916_Wing_Design_Fabrication_and_Analysis_for_an_X-Wing_Flapping-Wing_Micro_Air_Vehicle

An X-wing flapping-wing Micro Air Vehicle (FW-MAV) with a better payload carrying capability is designed, fabricated, and analysed in this paper. The wing design process was performed using a systematic approach to determine essential wing parameters. Two pairs of wings were fabricated using the traditional and advance mold methods. A prototype of FW-MAV is built by integrating the avionic system and assembling it with the wing, tail, and fuselage and gear system. The final mass of the FW-MAV was 36.9 g with a wingspan of 30.0 cm. Thrust measurement experiments were conducted using the load cell setup to measure the vertical thrust generated by the FW-MAV for different wings. By comparing these measurements, the results conclude that the FW-MAV produces the highest thrust at the pitch angle of 10◦, and wing 2 produces the highest vertical thrust of 86.75 g, compared to that of the wing 1 and the bird model wing. This preliminary study on designing a FW-MAV opens up opportunities to further investigate the feasibility of a fully autonomous flight of FW-MAV by designing a controller for this MAV.

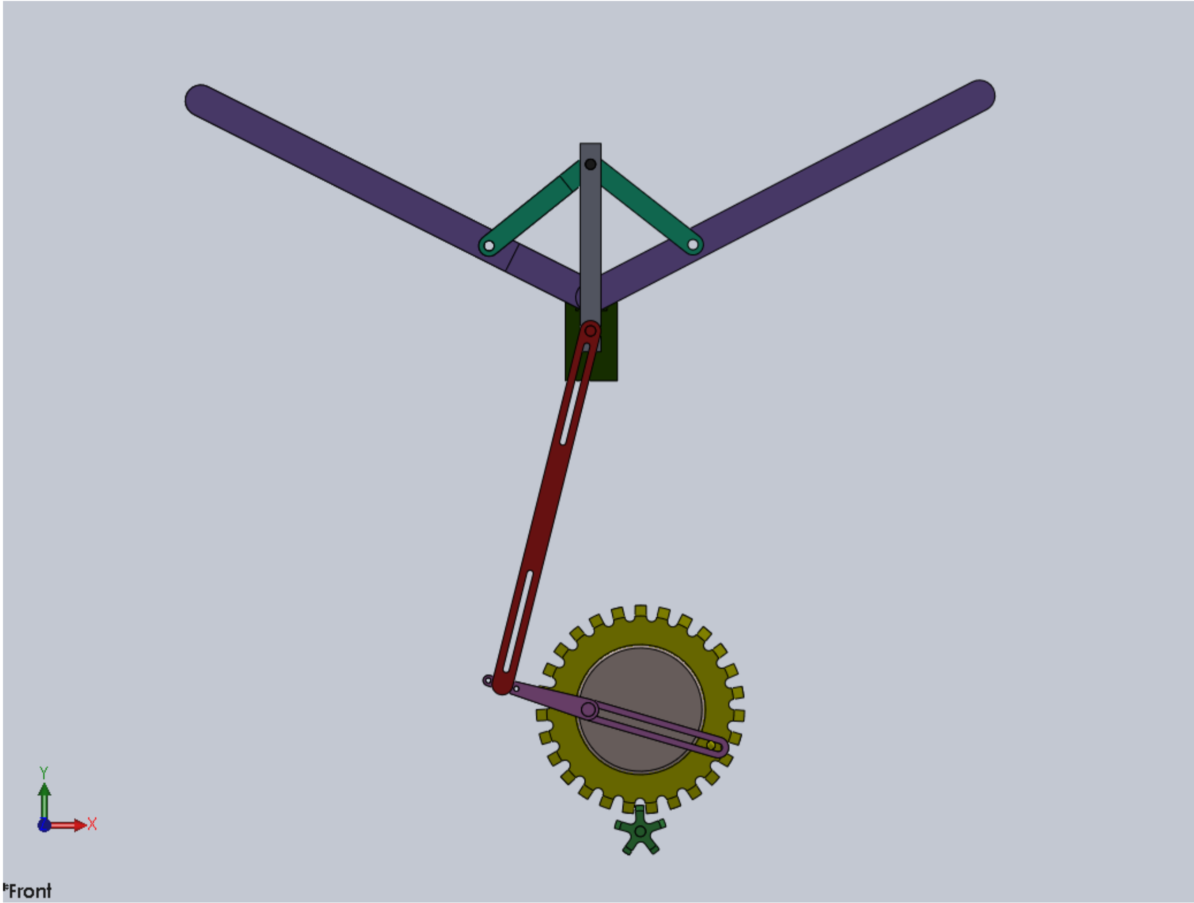
3D Model

The main parts used in the design are:

- Driving Gear (PCD 40,T=5)- Cast Iron
- Bull Gear (PCD 200, T= 25) Cast Iron
- Connecting Rod - Steel
- Slotted Pin - Steel
- Lever - Cast Iron
- Wings- Aluminum
- Connectors - Steel
- Bolt - Cast Iron

The driving gear is connected to the shaft of motor and is in mesh with the driven gear. The driven gear, connecting rod, slotted pin, and lever are connected such that they undergo Whitworth Quick Return Mechanism. The lever is connected to the wings above through some connecting pieces and bolts, such that they are able to flap.

The downward motion of the lever is slower so the upward motion of wings is slower whereas the upward motion of the lever is quick so the downward flapping of the wings is quicker, resulting in a net downward thrust, which produces the lift in the air vehicle.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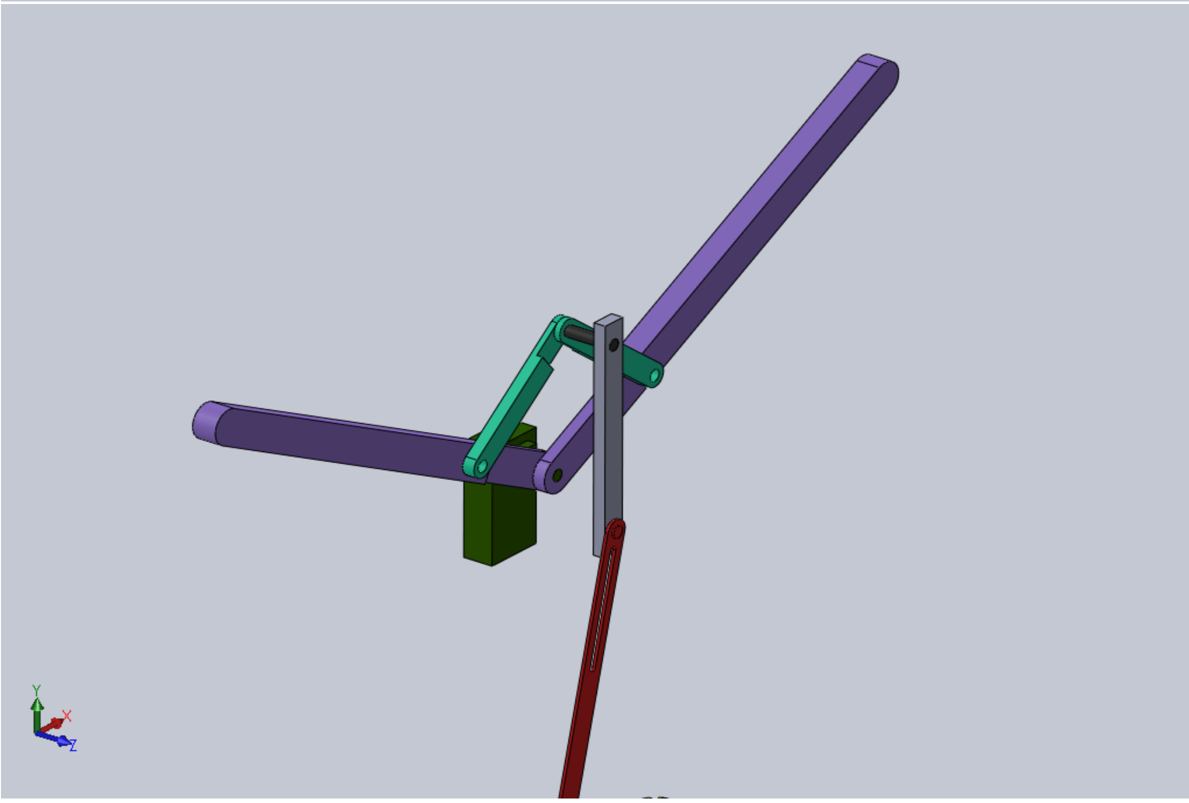
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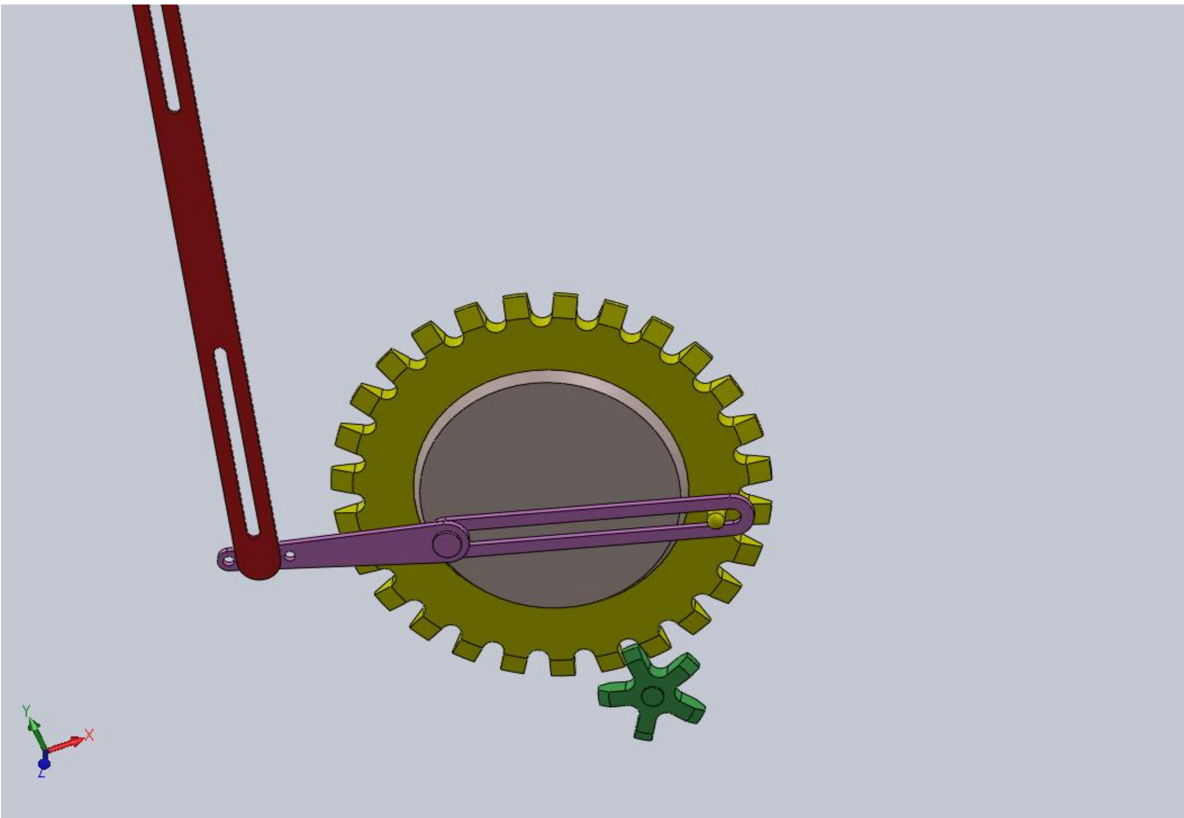
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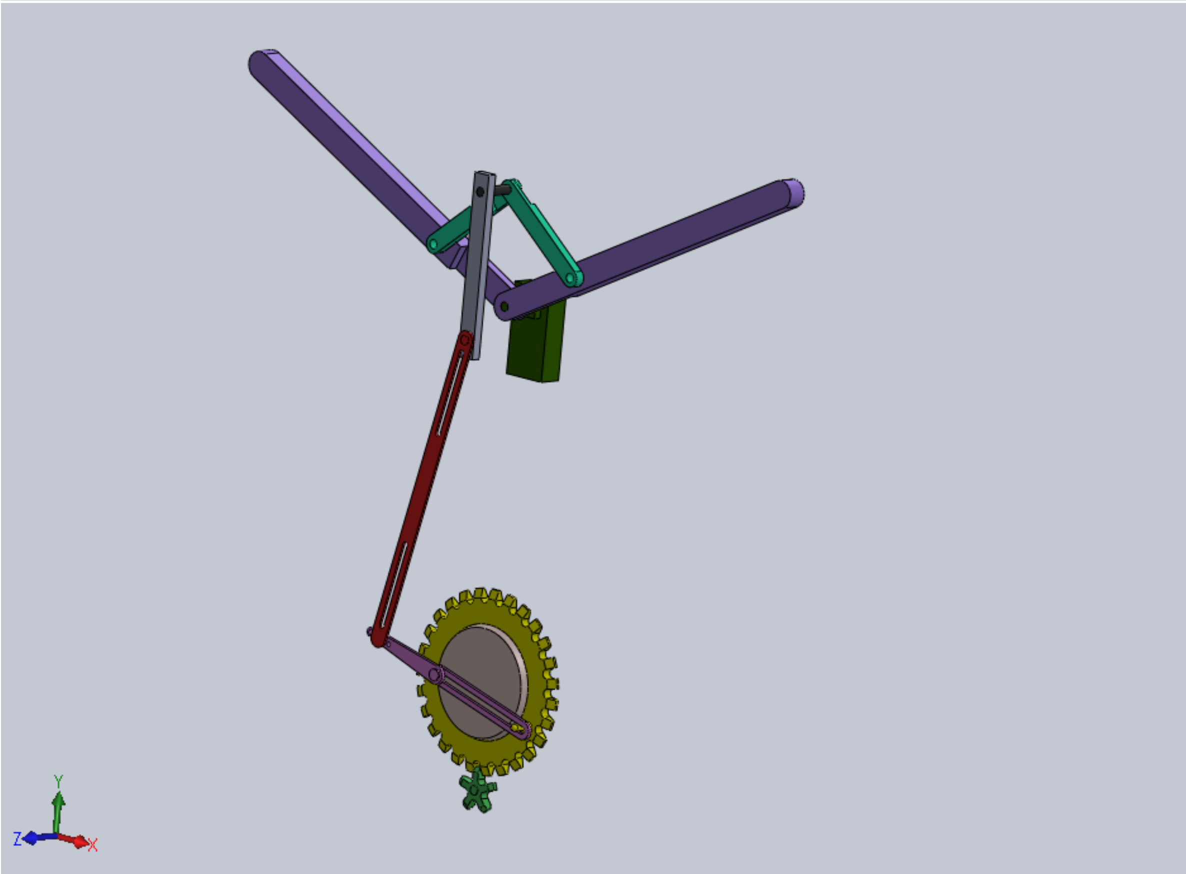
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Efficiency Comparison between Flapping Wing and Rotor based Air Vehicle

The mass of designed drone, M= 0.5kg.

Weight = M*g = 0.5*9.8 = 4.9 N.

So the minimum lift force 'L' to be provided is 4.9N.

Surface Area of each wing, S = 0.0120 m^2.

Density of air, ρ = 1.25 kg/m^3.

Angle of attack for rotor based air vehicle, α = 20 degrees = 0.35 rad.

Therefore, lift coefficient, $C_L = 2*\pi*\alpha = 2.2$.

For a drone designed with flapping wing mechanism:

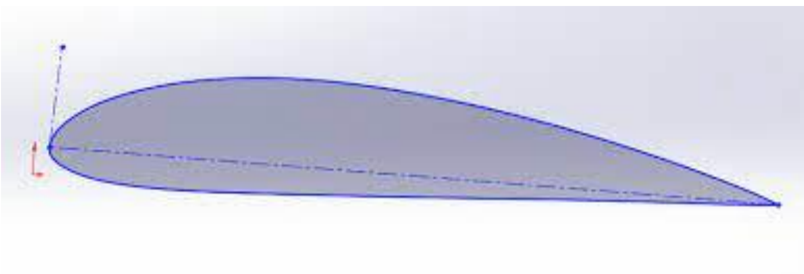
Relation used to find 'Lift' for flapping wings:

$L = 0.3*\rho*v^2*S$

$4.9 = 0.3*1.25*v^2*0.012$

Velocity of flight obtained, v= 33m/s.

For same drone designed in rotor blade mechanism:



Relation to find lift for normal rotor driven air vehicle:

$L = C_L*\rho*v^2*S/2$

$4.9= 2.2*1.25*v^2*0.012/2$

$v = 17.23$ m/s.

Keeping all other parameters same for both the designs, the power required is directly proportional to velocity of flight.

So, efficiency of flapping wings over rotor driven air vehicle:

$n = [(P_F – P_R)/ P_R] * 100$
$n = [P_F/P_R – 1]*100$

$n = [V_F /V_R – 1]*100$

$n= [33/17.23 – 1]$

$n= 91\%$

So for a micro air vehicle, we can see that flapping wings can be much more power efficient than rotor driven mechanism.

Conclusion and Future Scope of Work

In this project, we displayed how linkage mechanisms can be effectively used to design an air vehicle made to run on flapping wings. The main focus was to simulate a mechanism which can successfully be applied to obtain a working model of a flapping wing MAV, which we obtained using Whitworth's Quick Return Mechanism.

The idea of bio-inspired aircraft is already being explored a lot around the world but practical results has not been obtained yet at a large scale. If we dive more into the idea and explore parts like aerodynamics, body design, etc., a mechanized bird making our day to day tasks easier might not be too far in the future. This work presents an idea of what kind of mechanism might be used to obtain the desired machine, which may lay the foundation for further research on the same.

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