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DEVELOPMENT OF FLAPPING MECHANISM FOR MICRO AIR VEHICLE (MAV)

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ABSTRACT

The present work concentrates on development of flapping mechanism for Micro Air Vehicle (MAV). Initially two different flapping mechanisms were developed namely (i) sliding link mechanism and (ii) movable hinge mechanism. In sliding link mechanism it was found that there was unsymmetrical flapping. A mathematical model (using Visual Basic) was developed to study the flapping characteristics of the left and right wing in order to overcome the unsymmetrical flapping. Based on the mathematical model the movable hinge mechanism which produces symmetrical flapping was developed. Due to flexible movement of the strut of the movable hinge mechanism during flapping there was loss in motor torque. Recently a fixed hinge mechanism that is free from unsymmetrical flapping and strut movement was developed. Tests were conducted on both the mechanisms to study the characteristics of the flapping and the results were discussed.

Keywords: Flapping mechanism, Micro Air Vehicle, Movable hinge, Fixed hinge.

1. INTRODUCTION

Recent advances in micro-technology have created an opportunity to mount miniature surveillance equipment on small flying aircraft known as Micro Air Vehicles (MAVs). Such micro-technology includes tiny CCD cameras, infrared sensors and computer chip sized hazardous substance detectors. MAVs are used for both of military and civilian applications to gather information where human doesn't have access. There is increasing interest in the development of small MAVs, which can be used for outdoor flights as well as very small microscopic aircraft for indoor flights. Worldwide considerable work is in progress on miniaturizing the vehicle size for wide range of commercial and defence operations [1]. As per the DARPA (Defence Advance Research Projects Agency, USA) definition, the MAV size is expected to be of order the 10-15 cm, with total weight of 10-50 grams and the flight endurance of 20-40 minutes with payload (camera and transmitter) of 2 grams. MAV technology presents a variety of engineering challenges: they are (i) miniature propulsion, (ii) aerodynamics (iii) micro-electro mechanical systems (MEMS), (iv) small-scale power storage (battery), (v) avionics, (vi) flight controls and many others. The present work concentrates on the flapping wing propulsion.

1.1 Benefits of Flapping wing Propulsion

There are three basic concepts using which MAVs can be developed. They are (i) fixed wing category, (ii) rotary wing category and (iii) flapping wing category. Among these the flapping wing propulsion is the efficient way for MAV propulsion because it relies on lift produced by air flow (due to vehicle speed) and also wing flapping. Hence, when the size of the vehicle is reduced, the wing flapping frequency can be suitably adjusted [2,3]. This design is inherently forgiving for scale changes. Whereas, the fixed wing vehicles rely on the lift generated by the airflow passing over the wing. When the MAV size is reduced the wing area also gets reduced and the lift it generates is less. The energy requirement for the rotary wing vehicles are high compare to flapping flight. Another advantage of flapping vehicle is that they can take-off and land vertically at very short distances [4].

2. DESIGN OF FLAPPING MECHANISM

2.1 Input Parameters for Mechanism Development

The input parameters for the mechanism design are
1. Weight of the mechanism
2. The flap angle (ϕ)
3. Crank radius(r)
4. Width between the hinges (w)
5. Connecting rod length (h = l)

The general mechanism which gives the design parameters is shown in Fig 1.

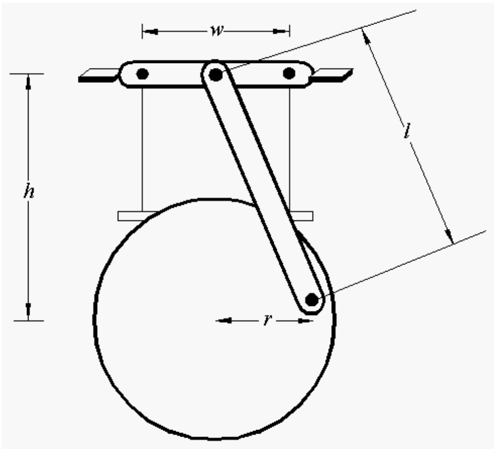

Fig 1. General Mechanism indicating various parameters

2.2 Features of the MAV Mechanism

The mechanism with unsymmetrical flap introduces a lag between the right and the left wings. The mechanism with symmetrical flap introduces no lag between the wings. Usage of unsymmetrical flap helps to maintain the uniform motor torque, thereby reducing the load on the motor. The unequal lift on the wings is a favorable condition to increase the motor torque. The main disadvantage is the lift produced by the wings is not same. This causes an oscillatory motion of MAV in the lateral direction. This type of unsymmetrical flap may be effectively used in the control of flight.

The use of symmetrical flap helps to get the same amount of lift on both the wings. This doesn't cause oscillatory motion in the lateral direction. Also obtaining the design parameters for the mechanism is simpler. The main disadvantage of this mechanism is the controllability. A separate control surface must be employed to achieve control in such mechanisms.

2.3 Mechanism Modeling

Before any mechanism is build, it is necessary to arrive at some approximate dimensions for the links in the mechanism. Hence a mathematical model has been developed. By varying the values of different parameters, the working of mechanism can be theoretically analyzed. Two mathematical models for the mechanism have been developed viz. the sliding link mechanism and the movable hinge mechanism.

The mathematical models can easily be developed using software like Visual Basic or Visual C++ or Turbo C graphics. In the present work the mathematical modeling has been developed using the Visual Basic Package (Fig 2). The values for various parameters like the crank radius, connecting rod length, tube diameter and hinge width are possible to vary at any instant in the model and thereby the animation of the mechanism. The maximum angle of flap, instantaneous angle of flap for each wing can be analyzed separately for every degree of crank rotation. The mathematical modeling is extremely useful in the development of flapping mechanism. The fabricated flapping mechanism closely resembles the mathematical model.

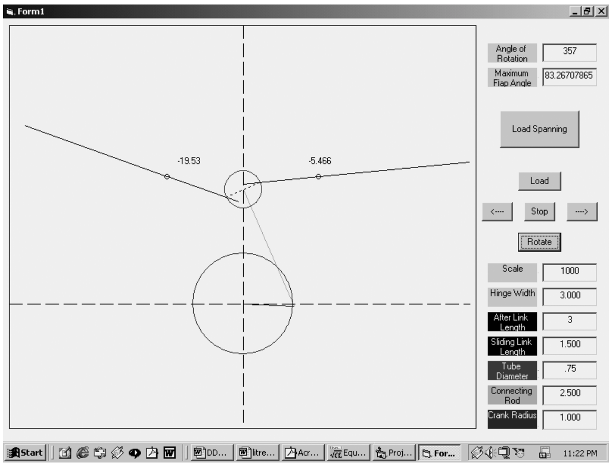

Fig 2. Mathematical Model of Sliding Link Mechanism

3. SLIDING LINK MECHANISM

3.1 Mechanism Description

The mechanism (Fig . 3) consists of a crank disk D attached to the motor shaft. One end of the connecting rod C is attached to the disc D. The tube has two holes through which the sliding links move up and down while the crank disc D rotates.

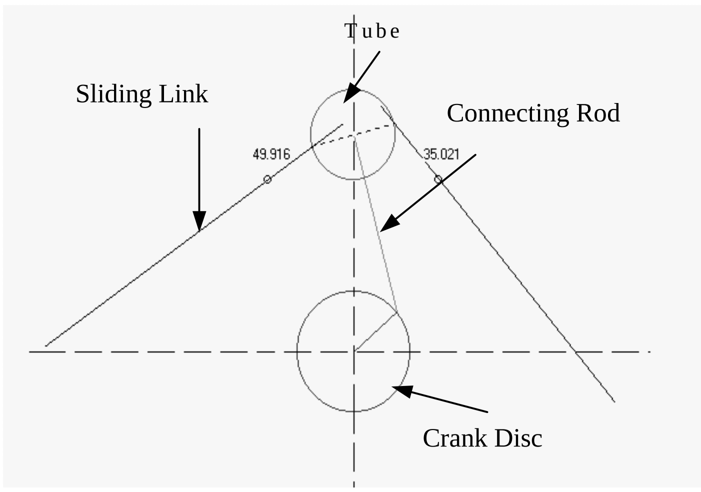

Fig 3. Sliding Link Mechanism

The sliding links are hinged at a distance of 25% of its length (experiments show that it could be hinged at 30-33%). The distance between the hinges is fixed. The height of the hinges from the base is also fixed. For the entire design the motor shaft position is taken as the origin. As the crank disc starts rotating, the links start sliding into the tube and gradually flaps down.

The main inputs for the design are the dimensions of various links of the mechanism. The dimensions are tailored to fit the total dimension of the mechanism. The dimensions of various links of the mechanism are shown in Table 1.

Table 1: Dimensions of sliding link mechanism

Component	**Dimension** (mm)
Hinge width (w)	30
Crank disc diameter (d=2xr)	20
Connecting rod length (*l*)	30
Tube diameter	10
Link length	30
Height of hinge from motor shaft	30

The main objective of the mechanism design is to have an optimum flapping frequency, angle of flap and minimum weight.

The maximum flap angle for the sliding link mechanism is given by

$$\phi = 2 * \mathrm{Sin}^{-1}\left(\frac{r}{0.5 * w}\right) \qquad (1)$$

and the maximum flap angle is 89.98°

3.2 Instantaneous Wing Rotation

The flapping angle of the wing greatly influences the instantaneous angle of attack of the wing and hence the lift and drag characteristics of the wing. If θ_i be the rotation of the crank then the tube T is displaced an height $r*sin(\theta_i)$ and the tube itself is rotated through an angle ψ_i. this in turn rotates the links.

The expression for the tube rotation is given as

$$\psi_i = \mathrm{Sin}^{-1}\left(\frac{(r* \cos(\theta_i))}{(h - r*sin(\theta_i))}\right) \qquad (2)$$

The instantaneous flapping angle of each of the wing is given as

$$\phi_i = \mathrm{Sin}^{-1}\left(\frac{(r * sin(\theta_i) \pm 0.5*t*sin(\psi_i))}{0.5w}\right) \qquad (3)$$

3.3 Wing Lag

In the unsymmetrical flapping mechanism it is observed that there is lag in the wing flapping between the right and left wings. The maximum lag is 17.93^0 when the crank is at right most position (0° crank rotation). As the crank rotation approaches (n+1)π/2 (n = 0,2,4…) the lag reduces to 0. This indicates that the flaps are nearly symmetrical only at the crank rotation angle (n+1)π /2 (n=0,2,4,..).

Table 2: Rotation of wings for rotation of crank

Crank Angle of Rotation θ^0	Right Wing Rotation $\phi_r^{\,0}$	Left Wing Rotation $\phi_l^{\,0}$
0.00	-0.27	-18.20
30.00	26.83	12.58
60.00	42.02	36.34
90.00	45.00	45.00
120.00	36.34	42.02
150.00	12.58	26.83
180.00	-18.20	-0.27
210.00	-37.09	-25.33
240.00	-44.55	-39.31
270.00	-45.00	-45.00
360.00	-0.27	-18.20

Table 2. shows the values of the angle through which the right and the left wings flap for each degree of crank rotation. The wing flapping positions are found to be same for 90° and 270° which are the points of maximum upstroke and down stroke. The design is such that the upstroke and the down stroke are equal and hence the flap angle at these positions.

3.4 Motor Specifications

The motor specifications influence more on the characteristics of the micro-air vehicle. The motor that has been selected for the mechanism has the following specifications.

Motor weight : 25.1g
Motor speed : 12000 RPM
Input voltage : 4.5 V

3.5 Weight of the Mechanism

The sliding link mechanism consists of links, motor and supportive frame. The links were made by the laminated composite material. The total weight of the mechanism is 37.9g without wings.

4. MOVABLE HINGE MECHANISM

4.1 Mechanism Description

The mechanism (Fig. 4) consists of a crank disk D attached to a motor shaft. One end of the connecting rod C is attached to the disk D. The other end of the connecting rod is attached to one end of the links L1 and L2 using fasteners. The other end of links L1 and L2 are connected to one end of flexible strut. The other end of struts is fixed at the base. The strut deflection makes the hinges to move while the connecting rod goes up and down

The distance between the hinges is fixed and so is its height from the base. For the entire design the motor shaft is taken as the origin. This helps in the calculation of velocity, acceleration and the axial/transverse forces act on various links. When the crank rotates the links start moving up and down. This link movement causes the wing flapping.

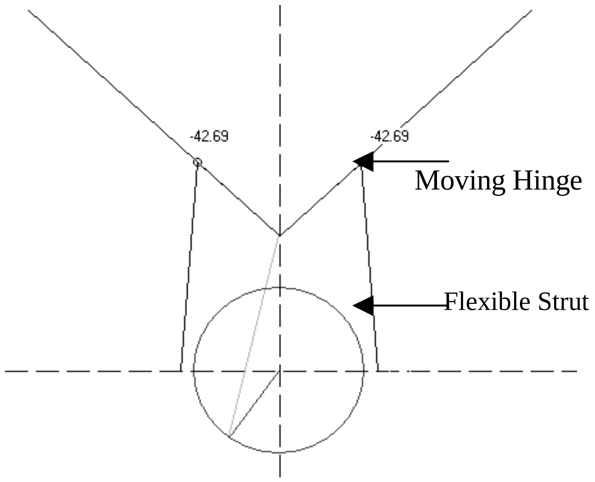

Fig 4. The Movable Hinge Mechanism

The design inputs are the dimensions of various links of the mechanism. The dimensions of the various links are given in Table 3.

Table 3: Dimensions of movable hinge mechanism

Component	Dimension (mm)
Hinge width (w)	25
Crank disc diameter (d=2xr)	20
Connecting rod length (*l*)	25
Link length	20
Height of hinge from motor shaft	25

The maximum flap angle for the movable hinge mechanism is given by

$$\phi = 2 * \mathrm{Sin}^{-1}\left(\frac{r}{0.5 * w}\right) \quad (4)$$

The maximum flap angle (ϕ) is 106.26^o. This is higher than the flap angle obtained in the sliding link mechanism.

4.2 Instantaneous Wing Rotation

The flapping angle of the wing greatly influences the instantaneous angle of attack of the wing and hence the lift and drag characteristics of the wing. Fig. 5 shows the instantaneous flapping angle and crank angle. If θ_i be the rotation of the crank then the crank rotation make the connecting rod to displace to an height $r*sin(\theta_i)$. The instantaneous flapping angle of the wings is given as

$$\phi_i = \mathrm{Sin}^{-1}\left(\frac{(r * sin(\theta_i))}{0.5w}\right) \quad (5)$$

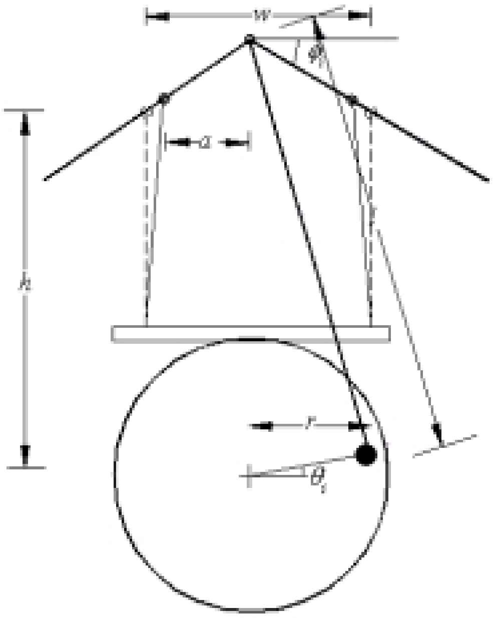

Fig 5. Movable Hinge Mechanism with Specifications

4.3 Wing Lag

There is no wing lag in the movable hinge mechanism and this contributes the symmetrical flapping.

4.4 Motor Specifications

The motor specifications influence more on the characteristics of the micro-air vehicle. The motor that has been selected for the movable hinge mechanism has the following specifications.
Motor weight : 20g
Motor speed : 12000 RPM
Input voltage : 1.5 V – 12.0 V

4.5 Weight of the Mechanism

The movable hinge mechanism consists of links, motor and movable struts. The links were made by laminated composite material. The total weight of the mechanism is 35g without wings.

5. FIXED HINGE MECHANISM

5.1 Mechanism Description

The flapping mechanism has been developed using Poly Vinyl Chloride (PVC) links and a small D.C. motor. In the MAV design the minimum weight criterion is very important. Hence a lightweight PVC having density (ρ) of 1.3g/cc has been selected for fabricating the links. The links have been flexibly connected using aluminum rivets of suitable sizes. In obtaining the maximum flap angle, the width between hinges (w) and crank radius (r) are the important parameters. The maximum flap angle (Φ) is attained by using the optimum values for 'w' and 'r' in the present design.

The mathematical expression used to determine the flap angle (Φ) is

$$\Phi = 2 * \tan^{-1}(r/w) \quad (6)$$

The maximum flap angle (Φ) obtained in the fixed hinge mechanism is 90^0.

The fixed hinge flapping mechanism is shown in the Fig 6.

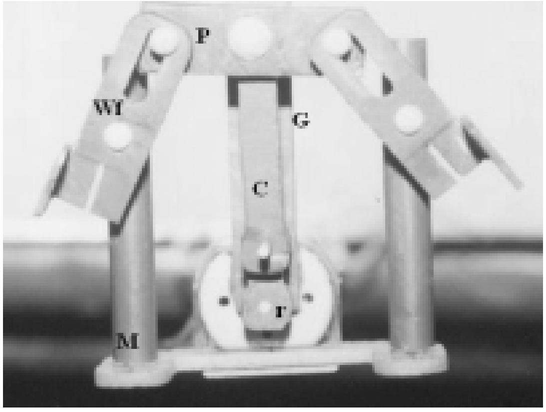

Fig 6. Fixed hinge Flapping Mechanism

The mechanism consists of a crank of radius (r) which is attached to the motor shaft and a connecting rod (C). One end of the connecting rod is attached to the crank and the other end is attached to the primary wing fixture plate (P), in which the linear motion is obtained through guide (G). Two wing fixtures (W_f) are used to mount the wings on the either side of the MAV. One end of both the wing fixture are connected on either sides of the primary wing fixture plate (P). The wing fixtures are supported by the main support (M), which is attached on the base of the MAV. The dimensions of the flapping mechanism components are given in Table 4.

Table 4: Dimensions of fixed hinge mechanism

Component	Dimension
Crank radius (r)	10 mm
Connecting rod C)	30 mm
Main support (M)	52.5 mm
Primary plate (P)	30mm x 8 mm
Wing fixture (W_f)	15mm x 8 mm
Guide (G)	52.5 mm

5.2 Wing Lag

In this mechanism there is no wing lag and this gives the symmetrical flapping.

5.3 Motor Specifications

The motor used for the fixed hinge mechanism has the following specifications.

Motor weight: 18g
Motor speed : 12000 RPM
Input voltage : 1.5 V – 12.0 V

5.4 Weight of the Mechanism

The weight of different components of the fixed hinge mechanism is given in Table 5. Comparing the sliding link and movable hinge mechanisms it has been found the fixed hinge mechanism weighs less (33 grams without wings).

Table 5: Weight of fixed hinge mechanism

Component	Weight (W) (g)
Crank radius (r)	0.5
Connecting rod C)	2
Main support (M)	3.5
Primary plate (P)	2
Wing fixture (W_f)	2
Guide (G)	2
Rivets	3
Motor	18
Total weight	33

6. RESULTS AND DISCUSSION

To measure the flapping frequency a non-contact type frequency-measuring instrument is developed using opto-coupler sensor and oscilloscope and it is shown in Fig 7. The D.C. motor characteristics for different input voltage are shown in Fig 8.

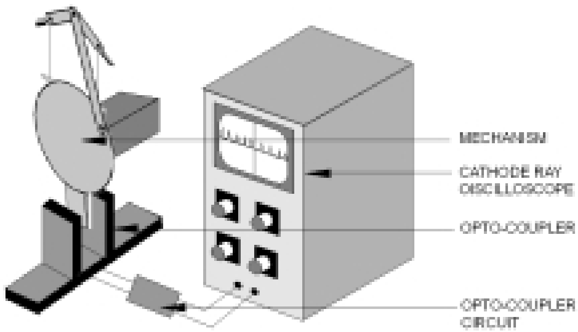

Fig 7. Opto- Coupler sensor arrangement

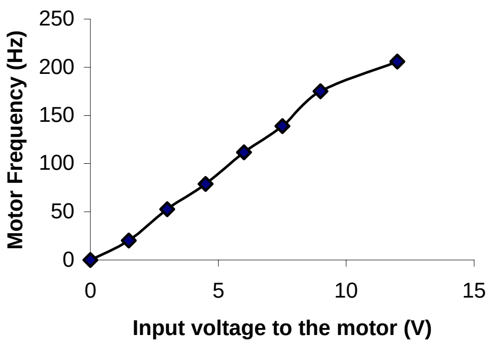

Fig 8. D.C. motor characteristics

Movable and fixed hinge mechanisms are tested using the above said instrument to determine the frequencies for different input voltage of the motor. The results are shown in Figs 9 and 10.

The experimental result shows that the movable hinge mechanism has high flapping frequency when the mechanism alone is connected to the motor (Fig 9) compare to the fixed hinge mechanism. The fixed hinge mechanism performs better when the wings are attached to the mechanisms (Fig 9 and 10) i.e., the difference in the flapping frequency is seen to be less than the flapping frequency of the movable hinge mechanism. In the movable hinge mechanism the wing attachment cause resistance to the deflection of the flexible strut. This may be due to the additional load on the strut due to the wing attachment. The additional load on the strut causes the reduction in the motor torque. The loss in motor torque reflects on the flapping frequency.

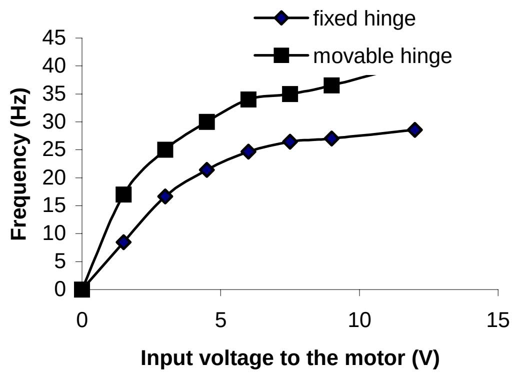

Fig 9. Flapping frequency characteristics of the mechanism

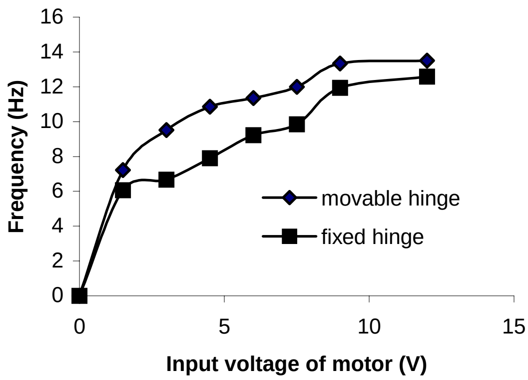

Fig 10. Flapping frequency characteristics of the mechanism with wing

7. CONCLUSION

Two different flapping mechanisms were developed. Mathematical model was developed for simulating the working of the mechanisms. Resistance to the deflection of the flexible strut by the wing attachment in the movable hinge mechanism was eliminated in fixed hinge mechanism. The flapping frequencies of the mechanisms were measured for different motor input voltage. From the experimental results it was found that the fixed hinge mechanism produce less flapping frequency due to more number of links in the mechanism. By minimizing the number and reducing the size of links it is possible to increase the flapping frequency in the fixed hinge mechanism.

8. SCOPE FOR FUTURE WORK

Weight of the flapping mechanism could be reduced by using micro motor. The links has to be miniaturized in order to reduce the width between the hinges that influences the maximum flap angle of the mechanism. The wings of different planforms have to be fabricated and the lift characteristics have to be studied [5,6].

9. REFERENCES

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10. NOMENCLATURE

Symbol	Meaning	Unit
ϕ	Flap angle	(degree)
r	Crank radius	(mm)
w	Hinge width	(mm)
W	Weight	(g)
θ_l	Tube rotation	(degree)
ψ_t	Wing rotation	(degree)
ρ	Density	(kg/m^3)
Hz	Frequency	(Hertz)
V	Voltage	(V)