PALLAVAN COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
MICRO AIR VEHICLE

AUTHORS

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INTRODUCTION

“Micro-Air Vehicles” (MAV) are small flying objects used for operations ranging from tactical military missions to normal commercial applications. The MAV’s have derived their name both from dimension and weight considerations. When the weight of a conventional aircraft and MAV are compared, the ratio is of the order of 10-6 and hence their name. The Defense Advanced Research Projects Agency (DARPA) has defined MAV as “fully functional military capable, small flight vehicles of size less than 15cm in length, width or height”[1]. MAV’s may use fixed or rotary or flapping wings, but the flapping wings use the combined advantage of the lift and thrust. The smaller the vehicle the less reasonable the fixed wing solution because fixed wing vehicles rely strictly on lift generated by airflow moving over the wing when the vehicle moving through the air to support the weight of the vehicle.

MECHANISM DEVELOPMENT

The mechanism for the MAV is of prime importance because; it affects the lift characteristics of the vehicle. The key factors like the angle of flap, flapping frequency, depend on the proper design of the mechanism. It is found that, a small DC motor provides cheap and easy/reliable way to build MAV mechanisms. DC motors are available as light as 2.3g which could be used in MAV design in order to scale down its weight.

MECHANISM DESIGN PARAMETERS

The key parameters for the mechanism design are

1. Angle of flap
2. Crank disk radius

\[
\phi = 2 \sin^{-1} \left( \frac{r}{0.5 \cdot w} \right)
\]

Where \( r \) is the crank radius and \( w \) is the width between the wing attachment hinges

Length of the connecting rods \( l = 2.5r \)
The height of the wing attachment hinges from the motor shaft, \( h = l \) \((l\) is the connecting rod length\)

![Diagram of the General Mechanism indicating various dimensions](image)

**Fig: The General Mechanism indicating various dimensions**

**MAIN FEATURES OF MECHANISMS**

**a. Unsymmetrical flapping motion**

**b. Symmetrical flapping motion**

1. The mechanism with unsymmetrical flap (Fig. 2a). This introduces a lag between the right and the left wings.
2. The mechanism with symmetrical flap (Fig. 2b). This introduces no lag between the wings.

The use of unsymmetrical flap helps to maintain the constant motor torque, thereby reducing the load on the motor. The lift due to the down stroke of the wing acts in a favorable direction as it increases the motor torque. The disadvantage is the unequal lift
produced by the wings at any instant. This causes an oscillatory motion in the lateral direction. This type of unsymmetrical flapping may be used in the control of flight. Symmetrical flapping produces equal lift on both the wings at all times. This does not cause any oscillatory motion along the lateral direction. The main disadvantage is the flight control while turning. This necessitates a separate control surface.

**MECHANISM MODELING**

Before any mechanism is build, it is necessary to arrive at some reasonable values and dimensions of the links. A mathematical model is developed to get reasonable values for the design parameters. By changing the values of different parameters, the working of the mechanism can be theoretically analyzed. The mathematical models for two mechanisms viz. the sliding link mechanism and the movable hinge mechanism have been developed.

In the present work the mathematical model has been developed using the Visual Basic Package (see Fig.). The model is developed using non-dimensional numbers. The values of various parameters like the crank radius, connecting rod length, tube diameter, hinge width could be instantaneously varied. The maximum angle of flap and instantaneous angle of flap for each wing could be analyzed individually for each degree of crank rotation. The values obtained for the design parameters using the mathematical model could be graphically presented. The mathematical modeling was extremely useful in development of flapping mechanism. The model used for experimental study closely resembled the mathematical model.

![Mathematical Model of Sliding Link Mechanism](image)
SLIDING LINK MECHANISM

The mechanism (Fig.) consists of a crank disk attached to the motor shaft. One end of the connecting rod is attached to the crank disk. The other edge of the connecting rod is flexibly connected with the tube. The tube has two holes drilled for the sliding link to pass through. The sliding links are hinged at a distance of 25% of its length at two different locations. 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 is considered as the origin. As the crank starts rotating, the links slide into the tube and starts flapping. When the crank completes one rotation, one flapping cycle would be completed.

![Fig: The Sliding Link Mechanism](image)

The initial inputs for the design are the dimensions of various links of the mechanism. The dimensions of the links are tailored to fit the total dimension of the mechanism.

Hinge width \( (w) = 3.0 \text{ cm} \)

Crank disk diameter \( (d=2*r) = 2.0 \text{ cm} \)

Connecting rod length \( (l) = 3.0 \text{ cm} \)

Tube diameter \( (t) = 1.0 \text{ cm} \), Total link length = 3.0 cm

Height of the wing attachment hinge from the motor shaft \( (h) = 3 \text{ cm} \)

MOTOR SPECIFICATION
<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>1/30</th>
<th>1/60</th>
<th>1/120</th>
<th>1/240</th>
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<tr>
<td>Tolerance Torque</td>
<td>g-cm</td>
<td>300</td>
<td><strong>420</strong></td>
<td>600</td>
<td>600</td>
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<tr>
<td></td>
<td>N-cm</td>
<td>2.94</td>
<td><strong>4.12</strong></td>
<td>5.88</td>
<td>5.88</td>
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<tr>
<td>Rated Torque</td>
<td>g-cm</td>
<td>250</td>
<td><strong>350</strong></td>
<td>500</td>
<td>500</td>
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<tr>
<td></td>
<td>N-cm</td>
<td>2.45</td>
<td><strong>3.43</strong></td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>min⁻¹</td>
<td>310</td>
<td><strong>175</strong></td>
<td>85</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>(r.p.m.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated Current A:</td>
<td>mA</td>
<td>350</td>
<td><strong>300</strong></td>
<td>240</td>
<td>170</td>
</tr>
<tr>
<td>Rated Current B:</td>
<td>mA</td>
<td>180</td>
<td><strong>160</strong></td>
<td>120</td>
<td>90</td>
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<tr>
<td>No Load Speed</td>
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<td>390</td>
<td><strong>210</strong></td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>(r.p.m.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stall Current A:</td>
<td>mA</td>
<td></td>
<td></td>
<td>1300</td>
<td></td>
</tr>
<tr>
<td>Stall Current B:</td>
<td>mA</td>
<td></td>
<td></td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>g</td>
<td>25</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

**MOVABLE HINGE MECHANISM**

The mechanism shown in Figs.7a and 7b consists of a crank disk attached to the motor shaft. One end of the connecting rod is attached to the disk. The other end of the connecting rod is connected to one end of links L1 and L2 using fasteners. The Links L1 and L2 are held in position by the flexible strut from the base.

It is known that the links are rigid. If the hinges are placed at fixed positions, the links will not move up and down freely. This problem is over come by making the hinges
move freely. The free movements of the hinges are obtained by attaching the hinges on the flexible struts.

Hinge width (w) = 2.5 cm
Crank disk diameter (d=2*r) = 2.0 cm
Connecting rod length (l) = 2.5 cm
Total link length = 2 cm
Height of the wing attachment hinge from the motor shaft (h) = 2.5 cm

Movable Hinge Mechanism

DEVELOPMENT OF FLAPPING WINGS

The constraints in design of wings are

i) MAVs must have a wingspan of 15 cm by its definition.

ii) If the MAV is to mimic natural flyers then it has to fly by flapping wings.

Unfortunately, aerodynamics of flapping wing flight, especially MAV size, is still not fully-explored. Studies have been carried out on insect flights however there have not been any available design rules for flapping-wing aerodynamics for MAV, like fixed wing aerodynamics.

MECHANISM PARAMETERS:

Maximum Angle of Flap (\(\theta\)): 60°
Dihedral Angle ($\Phi$) : 10°
Bend Angle ( $\Phi$ ) : 160°
Hinge Width (w) : 60 mm
Connecting Rod Length (l) : 37 mm
Crank Radius (r) : 15 mm

WING PLANFORMS

Four pairs of wing planforms, A, B, C and D [2] from the literature and two pairs of new wing planforms E and F are used for the present study. The wing area and the aspect ratio are same for all the wing planforms. Table 1 gives salient features of the wings. The spars are made out of epoxy impregnated carbon fiber. The spars are placed at pre-determined angles and bonded to the poly-ethylene using skin.

Various Wing Planforms Used

<table>
<thead>
<tr>
<th>WING PLANFORM</th>
<th>SPAR ANGLE</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Mid Spar oriented at 45°</td>
<td>Total weight, W</td>
</tr>
<tr>
<td>B</td>
<td>No Mid Spar</td>
<td>Forward velocity, U</td>
</tr>
<tr>
<td>C</td>
<td>Mid Spar oriented at 10°</td>
<td>Flapping frequency, f</td>
</tr>
<tr>
<td>D</td>
<td>Mid Spar oriented at 10°</td>
<td>Wingspan, b</td>
</tr>
<tr>
<td>E</td>
<td>Mid Spar oriented at 20°</td>
<td>Flapping Amplitude, $\Phi$</td>
</tr>
<tr>
<td>F</td>
<td>Mid Spar oriented at 45°</td>
<td>Thrust, T</td>
</tr>
</tbody>
</table>

Testing of the flapping mechanism for the MAV (Fig) has been carried out with six different
wing planforms. To measure the lift, strain gauge based instrumentation has been developed. The instrumentation is calibrated for its output by gradually applying the known force. In order to simulate various free stream velocity a low Reynolds’s number air blower with speed control has been used. The air speed is calibrated by varying the known input power supply to the blower.

PRECAUTIONS

The flapping frequency of the MAV is fixed to a particular value and maintained as same for different free-stream velocities. The experiment is repeated by varying the flapping frequency.

RESULTS AND DISCUSSIONS

Figs. below give the overall characteristics of the lift produced by the MAV at different free-stream velocities. The tests were conducted at five different flapping frequencies. For each flapping frequency free-stream velocity has been varied from still air to 6 m/s. The lift variation for the different free-stream velocities for a particular
flapping frequency is plotted. The experiments were repeated for different wing planforms and the lift characteristics are plotted.

It is observed that the lift is mainly due to wing flapping when the free-stream velocity is zero (i.e. in still air). At higher free stream velocity the lift not only depends on the wing flapping but also depends on the wing aerodynamics. The lift of the MAV increases when the free-stream velocity increases and the general trend has been the same for all the wing planforms.

Though all the wings have the same wing area and aspect ratio, they do not have the same lift characteristics.
Lift Characteristics of Wing C

Lift Characteristics of Wing E

Lift Characteristics at 16Hz Flapping Frequency
CONCLUSION

Flapping wing MAV’s is an alternative to conventional fixed wing MAV because of its increased efficiency, maneuverability and stealth in nature. In particular, flapping wing deforms aero elastically into an efficient shape is quite effective and simple to construct. The main problem is the development of a wing capable of producing enough thrust and lift to drive a small MAV.

The various inputs for the design have primarily been derived from natural flyers of the MAV size. Based on these inputs the mechanism for flapping and the suitable wing were designed to support the weight of the MAV. It was found that the shape of the wing to a larger extent dictates the lift characteristics of the MAV. The present work addresses the challenges involved in the design and construction of a small, light flapping mechanism. Two flapping mechanisms were developed and the movable hinge mechanism with symmetrical flapping was used to test the wing performance.

SCOPE FOR FUTURE WORK

Wing performance may be more accurately predicted if three-dimensional aerodynamic effects are examined. The mechanism can be optimized by reducing the weight of the motor with increase in torque. Wing shapes with spans less than 15cm can be tested to study the effect of shapes. High efficiencies may be achieved if the spar with optimum stiffness distribution is used instead of the one with uniform stiffness. Theoretical study using the unsteady panel method will help the actual wing design. The tailoring of the flexural axis to the aerodynamic characteristics is an important aspect towards the design of aero elastic wing.

REFERENCE:
[1] J. McMichael and J. Francis titled "Micro air vehicles - Toward a new dimension in flight." Robotics and Intelligent Machines Laboratory, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA.