Design And Construction of An Autonomous Ornithopter

Under the Guidance Of Prof. Santosh Rathore

Department of Mechanical Engineering (SRPEC)

By
Vaibhav Modi (12ME94)
Akshay Shah (12ME99)
Acharya Kuldip(12ME101)
Nikul Modi(12ME93)

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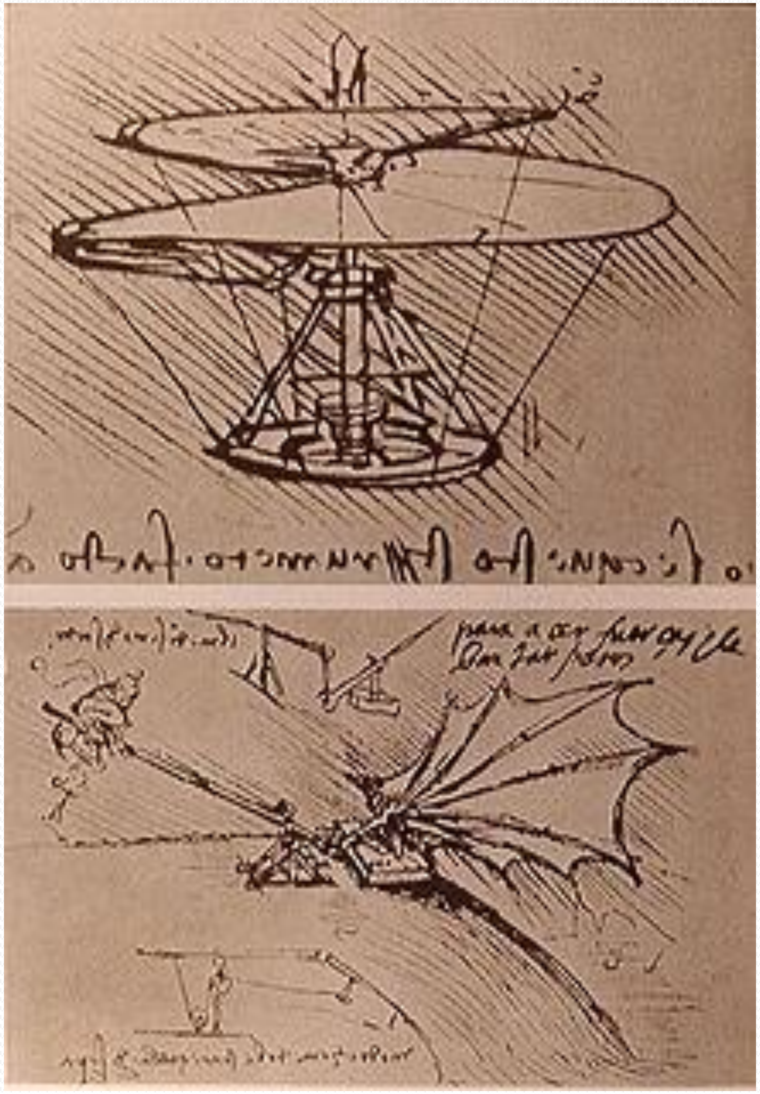
Abstract:

- In recent years the subject of flying vehicles propelled by flapping wings, also known as ornithopters, has been an area of interest because of its application to micro aerial vehicles (MAVs). These miniature vehicles seek to mimic small birds and insects to achieve never before seen agility in flight. In order to better study the control of flapping wing flight we have developed a large scale ornithopter called the Phoenix. It is capable of carrying a heavy (400gram) computer and sensor package and is designed specially for the application of controls research. The design takes special care to optimize payload capacity, crash survivability, and field repair abilities.

Project Background:

- . In 1485, Leonardo da Vinci began to study the flight of birds. He grasped that humans are too heavy, and not strong enough, to fly using wings simply attached to the arms.
- He therefore sketched a device in which the aviator lies down on a plank and works two large, membranous wings using hand levers, foot pedals, and a system of pulleys.



- Around 1960, Percival Spencer successfully flew a series of unmanned ornithopters using internal combustion engines ranging from 0.020-to-0.80-cubic-inch (0.33 to 13.11 cm^3) displacement, and having wingspans up to 8 feet(2.4m)
- In 1961, Percival Spencer and Jack Stephenson flew the first successful engine-powered, remotely piloted ornithopter, known as the Spencer Orniplane
- It had a 2300mm of wingpan and 3.4 kg in weight.

Introduction:

- Natural fliers like birds and insects have captivated the minds of human inventors through history. The ease and grace with which they take to the air vastly surpasses the state of the art in aircraft and their control systems.
- This is not to say that modern aircraft designs are ineffective, they are excellent in many respects. Propellers and turbines are very efficient methods of producing thrust and air foils efficiently produce lift.
- Interest in the design and control of ornithopters has grown in recent years as interest has grown in the area of Micro Aerial Vehicles or MAVs.

Literature review:

1)Charron Richard:

- An ornithopter has a power assembly Which provides flapping of the Wings by a reciprocating shaft and bell cranks. The Wings are mounted on a hub Which rotates in response to the flapping of the Wings. The sinusoidal movement of the Wings provides lift for flight.

2)Keennon et.al.:

- Heavier-than-air, aircraft having flapping wings, e.g., ornithopters, where angular orientation control is effected by variable differential sweep angles of deflection of the flappable wings in the course of sweep angles of travel and/or the control of variable wing membrane tension.

3)Fuchiwaki et.al.:

- Duration of upstrokes of the left and right Wings is shorter than duration of downstrokes 0f the same to generate lift forces.

4)Konrad Gar:

- A flapping wire aircraft capable of being operated by manpower comprising double wings acting in a countermovement is provided with a toggle lever system on each side for separate actuating the right-hand and left hand wings respectively to improve steering possibilities.

5)Richard Charron:

- An ornithopter has the capability of slow speed flight as a result of vertical movement of its Wings. Two sets of Wings are provided With vertical movement of each set of Wings 180 degrees out of phase for counterbalancing vertical forces on the fuselage.The direction of the flight path is changed by deflecting the fuselage.

6)Andrew Sean Kinkade:

- Each Wing may include a generally triangular inner Wing portion and a generally triangular outer Wing portion. The outer Wing portion may have a plurality of spaced apart battens extending between the diagonal stiffening member and the trailing edge.

Objective:

- Ornithopters can be made to resemble birds or insects, they could be used for military applications such as aerial reconnaissance without alerting the enemies that they are under surveillance.

- Several ornithopters have been flown with video cameras on board, some of which can hover and maneuver in small spaces

Scope of project:

- As demonstrated by birds, flapping wings offer potential advantages in maneuverability and energy savings compared with fixed-wing aircraft, as well as potentially vertical take-off and landing. It has been suggested that these advantages are greatest at small sizes and low flying speeds.

- As compare with helicopters, the wings usually have a combined function of providing both lift and thrust. Theoretically, the flapping wing can be set to zero angle of attack on the upstroke, so it passes easily through the air.

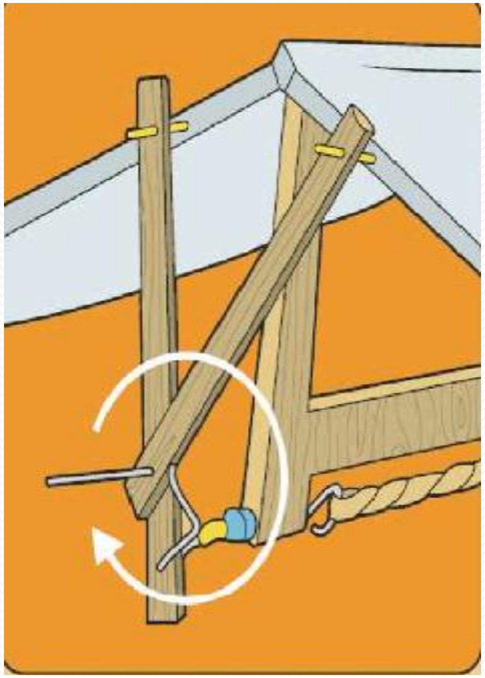
Methodology:

- Prototype Building
- Construction of Our Ornithopter

1. Main frame
2. Electronics
3. Wings
4. Gear Box
5. Tail

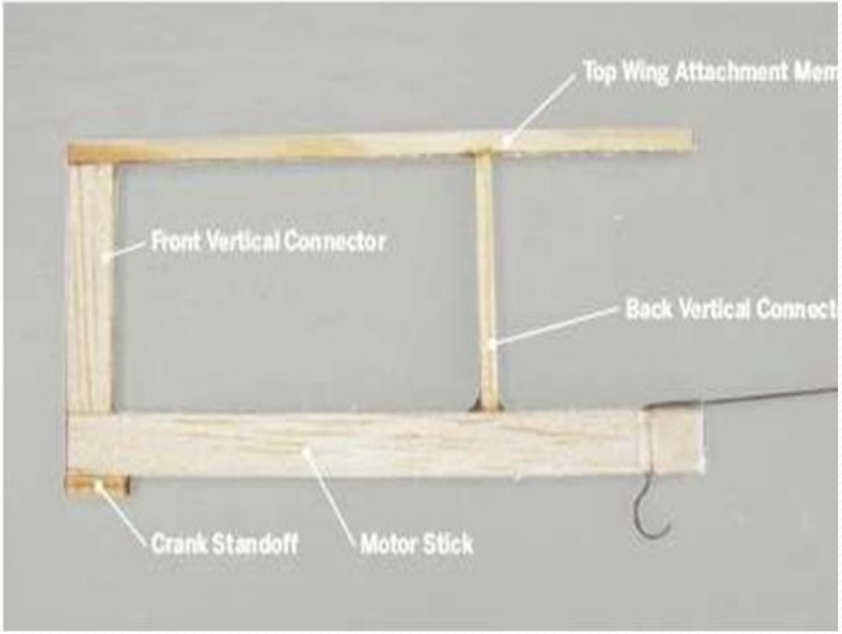
Prototype Building:

- According to Nathan Chronister of online Ornithopter Zone: The ornithopter wing is attached at a slight angle , which is called angle of attack . The Downward stroke of the wing deflects air downward and backward, generating lift and thrust.
- Also, the wing surface is flexible. This causes the wing to flex to the correct angle of attack we need in order to produce the forces that we want to achieve flight.

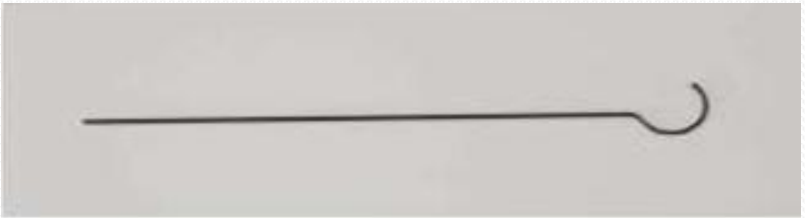


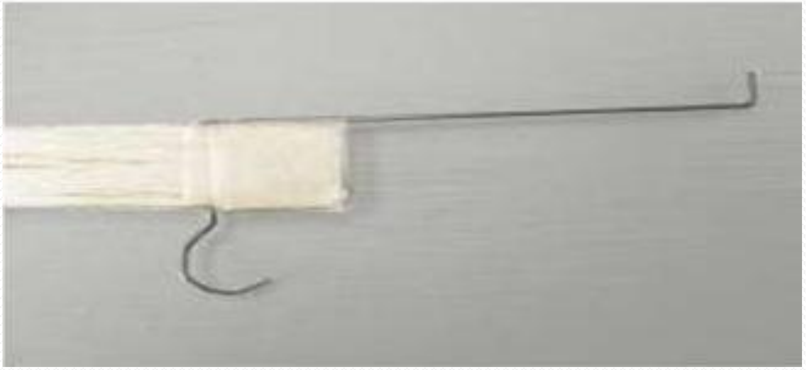
Wings mechanism of prototype

Body of Prototype:



Wire Assembly:

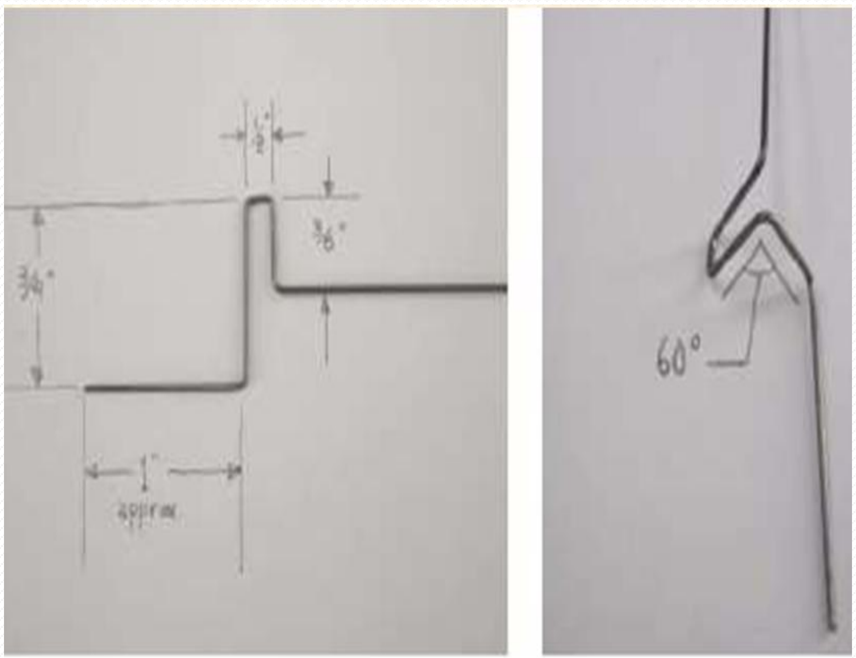




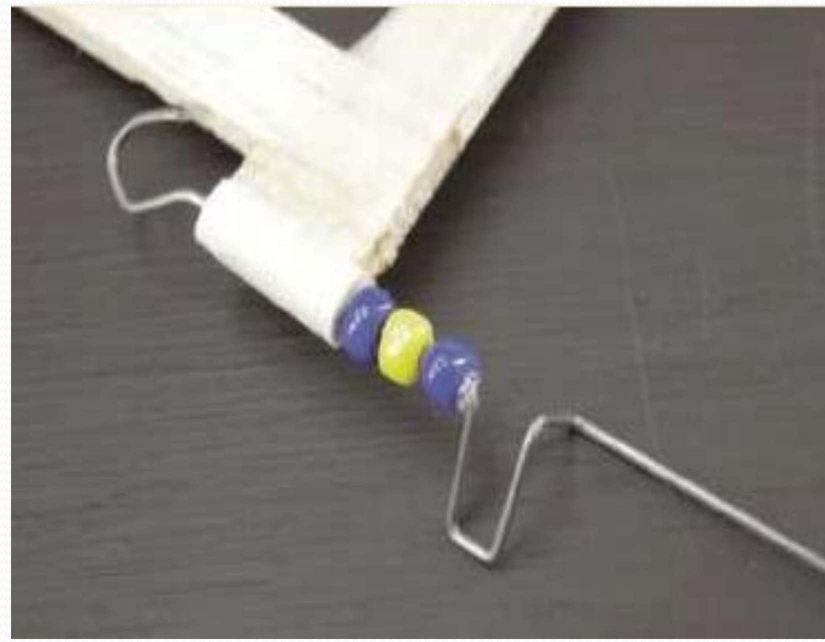
Wire wrapping:

Frame:

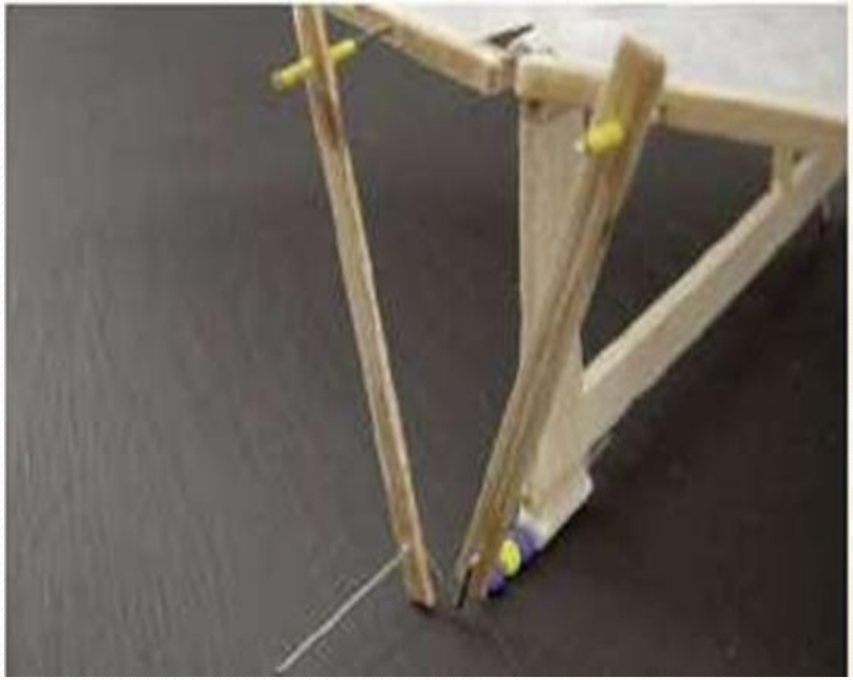
Wire bending:



Assembly:



Connecting rod:



Tail:

full frame:

Working of connecting rod:

Full prototype:

Construction of Our Ornithopter:

- Main frame
- Electronics
- Wings
- Gear Box
- Tail

Main Frame:

- For construction of main frame the material selection was an important thing. As the weight of material and its strength are very important factor for this project.
- It is liable to use Carbon Fiber in order to obtain light weight structure. BT it is rarely available and the cost is also high. So we started finding the alternatives of Carbon Fiber. This disadvantage of Carbon fiber is been dismissed by Balsa wood. It a type of wood with very light weight, can be comparable with Thermocole but strength is good. so we decided to use Balsa wood for our structure.

Comparison between balsa wood and Carbon Fiber:

Constraints	**Balsa Wood**	**Carbon fiber**
Density	0.13gm/cm3	1.4gm/cm3
Dielectric Strength	4.5kv/mm	30kv/mm
Elastic Modulus	3Gpa	10Gpa
Elongation	1.2%	1.4%
Strength to Weight	110kNm/kg	150KNm/kg
Thermal Expansion	16.5 *10^-6m/mk	0.4*10^-6m/mK

Balsawood:

- **Common Name(s):** Balsa
- **Scientific Name:** Ochroma pyramidale
- **Distribution:** Tropical regions of the Americas; also grown on plantations
- **Tree Size:** 60-90 ft (18-28 m) tall, 3-4 ft (1-1.2 m) trunk diameter
- **Average Dried Weight:** 9 lbs/ft^3 (150 kg/m^3)
- **Specific Gravity (Basic, 12% MC):** .12, .15
- **Modulus of Rupture:** 2,840 lb_f/in^2 (19.6 MPa)
- **Elastic Modulus:** 538,000 lb_f/in^2 (3.71 GPa)
- **Crushing Strength:** 1,690 lb_f/in^2 (11.6 MPa)
- **Shrinkage:** Radial: 2.3%, Tangential: 6.0%, Volumetric: 8.5%, T/R Ratio: 2.6

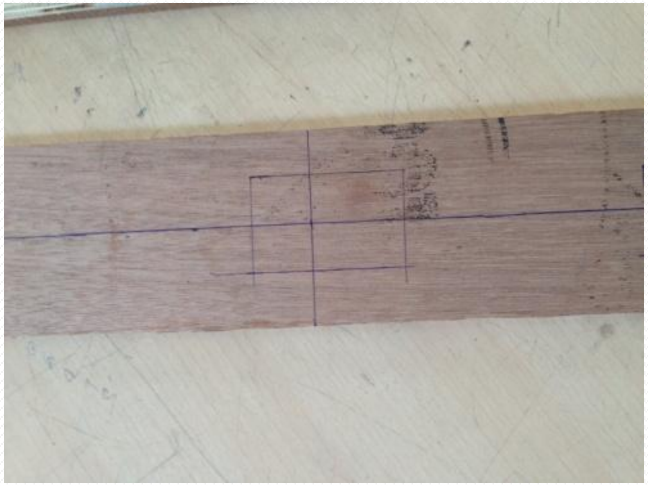
- **Color/Appearance:** Heartwood tends to be a pale reddish brown color, though it is not commonly seen in commercial lumber.
- **Grain/Texture:** Balsa has a straight grain with a medium to coarse texture and low natural luster.
- **Rot Resistance:** Sapwood is rated as perishable, and is also susceptible to insect attack.
- **Sustainability:** This wood species is not listed in the CITES Appendices or on the IUCN Red List of Threatened Species.

- **Common Uses**: Rafts, surfboards, model airplanes, musical instruments, packing/transport cases, core stock in sandwich laminations, and fishing lures.
- **Comments***:* Balsa is a wood that is famous worldwide. And while its density and mechanical values can vary significantly depending on the growing conditions of any particular tree, it is generally the lightest and softest of all commercial woods, ranging from 8 to 14 pounds per cubic foot. Yet despite its softness, Balsa is technically classified as a hardwood, rather than a softwood, since it has broad leaves and is not a conifer.

Balsa wood Properties Guide:

Density	163+-10kg/m3
Compressive strength Low Density Medium Density High Density	 4.7Mpa 12.1Mpa 19.5Mpa
Tensile Strength Low Density Medium Density High Density	 7.6Mpa 19.9Mpa 32.2Mpa
Elastic Modulus- Compression Elastic Modulus-Tension	460+-71Mpa 1280+-450Mpa

- Therefore the material is now selected and it is to design the frame.



1st design

Real design

- **1st Design:** During design of frame the distribution of C.G is major constraint. In 1st design all the components are located at centre so its C.G gets disturbed. While flying it will create problem so this design gets cancelled.
- **Real Design:** As 1st design got rejected due to C.G distribution in this design the C.G is not disturbed and the components are fitted at front and rear end. So it gets balanced and will not create any problem while flying.

Electronics:

- While the electronics on the ornithopter are not a critical system as far as the mechanical functions of the machine performs they do make up the one of the most important specifications for the project, the minimum payload capacity. Because the rest of the sizing and designing of the ornithopter depends on this and the weight of the computer, interface equipment, sensors, and battery must be determined first.

Battery:

- Li-po 11.1v 2200Mah battery

Battery Specs	
Voltage	11.1V Nominal - 12.6V Max
Capacity	2200mAh
Cell Count	3
Size	25 x 34 x 104 mm
Weight	183 Grams
Max Continuous Discharge	30C
Max Continuous Discharge Current	66A
Recommended Charge	1C
Recommended Charge Current	2.2A
Power Connector	Female T-Connector (Deans Ultra Plug compatible)
Balance Connector	Standard JST - 4 Pin(.1"/2.54mm)

Wings:

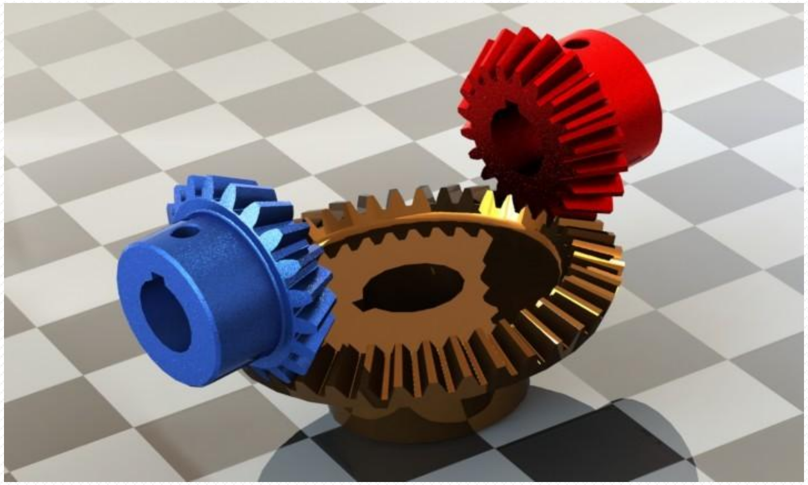
- Here the wings are made up of Balsa material. They are 540mm in length and 150 mm in height and 6mm in thickness. They are connected from front end of frame to rear end so as to covered whole body in order to create high lift force.

Gearbox:

- Many types of gears are available in market in order to reduce or increase the speed.
- The types of gear that can be used are as follows
- Bevel Gear
- Spur Gear
- Helical Gear
- Herringbone Gear

- The most favorable gear in this case is Bevel Gear.

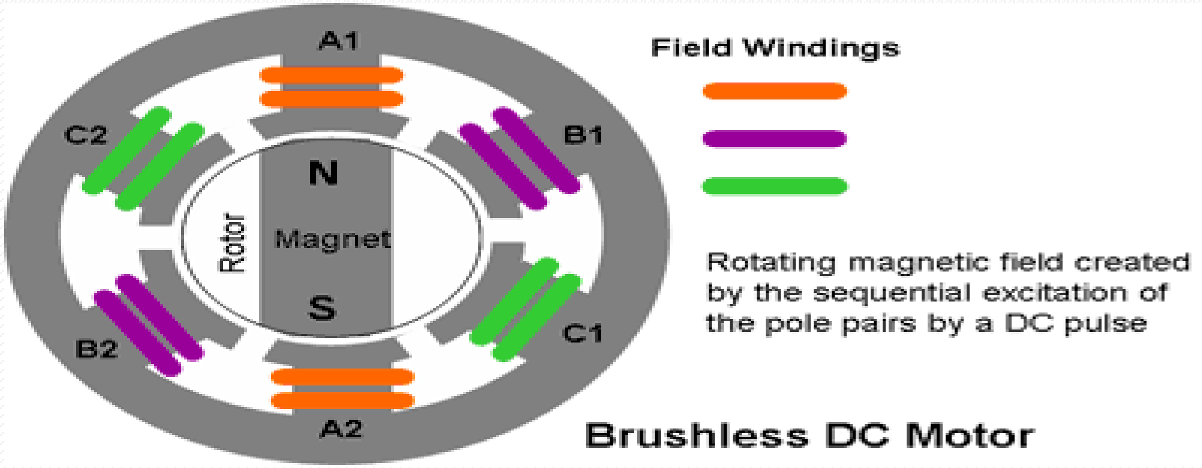
Bevel Gear:



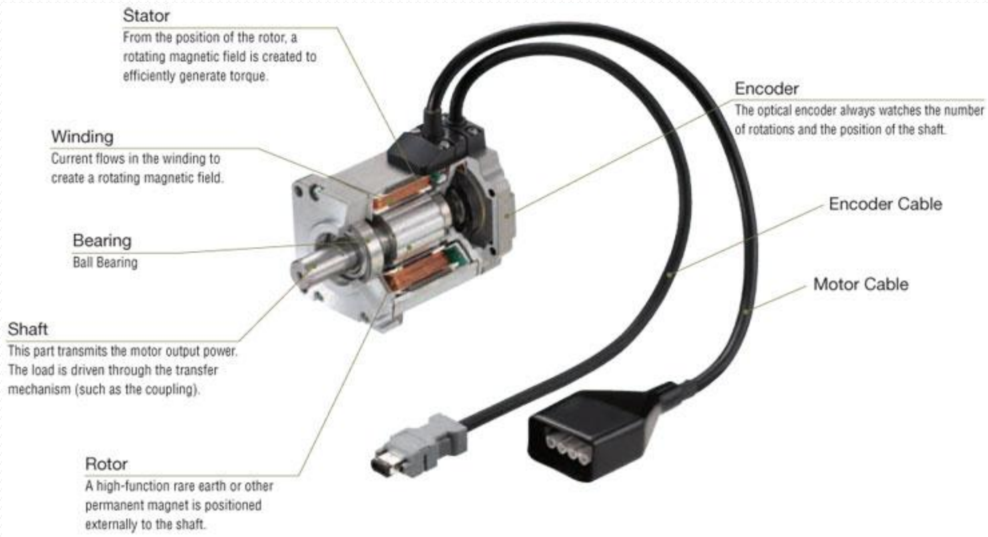
- Selection of bevel gear is good due to its good power transmitting capacity and availability of manufacturer. But we faced some problems relating to its speed control and manufacturing. We wanted very small size of gear for mechanism .
- With bevel gear we were using quick return mechanism so that rotary motion will get transmitted to reciprocating motion. By using reciprocating motion we are trying to control both wings so that due to both driving wings more lift force will get created and ornithopter might take flight.

- But the construction of small size gear was very costly and our project was going out of budget so we decided not to use it. Another problem we faced was controlling the speed of BLDC motor. While using 1000kv motor with combination of bevel gear and quick return mechanism the structure broke down. Because with 11.1 V battery the RPM of 1000kv became 11000rpm and balsa was not able to took that high load so that design failed.
- So we started finding alternative arrangement for construction of Ornithopter.
- At last it was decided to remove gear mechanism as it was making the structure complex and adding more weight. So direct power supply was transmitted from motor to Wings.

Motor Selection:

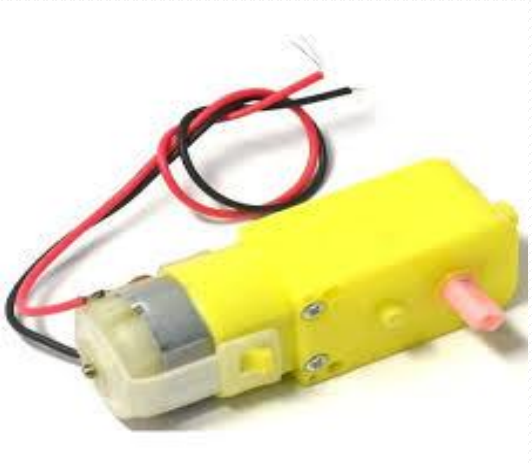


- **BLDC motor:**
- Brushless motors may be described as stepper motors; however, the term "stepper motor" tends to be used for motors that are designed specifically to be operated in a mode where they are frequently stopped with the rotor in a defined angular position. This page describes more general brushless motor principles, though there is overlap.



- **SERVO MOTOR:**
- A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.
- Servomotors are not a specific class of motor although the term *servomotor* is often used to refer to a motor suitable for use in a closed-loop control system.
- Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.

- **BO MOTOR:**
- Two types of BO motor are available Type –I and Type-L
- These motors are available in different speed range i.e 60rpm, 100rpm, 150rpm etc. These motors are also available with different voltage requirement.



I-type BO motor

L-type BO motor

The motor which we have used has following specifications:

Voltage	3-9v
CURRENT	0.01A(no load);0.07A(at max load)
LOCKED-ROTOR CURRENT	>=0.15
SPEED(RPM)	60RPM+-10%(NO LOAD)
TORQUE	0.5Kg-cm
ROTATION	CW/CCW
MOUNTING TYPE	Horizontal or Vertical

Tail:

- The tail section of the ornithopter is responsible for both of the controllable degrees of freedom as well as from the ability to throttle the drive motor. The tail can provide aerodynamic shape to the structure. Its function is to change the direction while flying. The tail of Aero plane has also the same function to perform.
- But here in this case as the Ornithopter is not able to take flight due to the above discussed reasons here the tail section is clamped just in order to give it a shape of bird.

Principal Of Ornithopter :

- Three Forces are acting on the ornithopter in its working condition
- 1. Weight Force (mg)
- 2. Buoyancy Force ($\rho g v f_d$)
- 3. Drag Force($\rho A v^2$)

Total Force= weight + Buoyancy+ Drag
Force Force Force

$$F = mg + \rho g v f_d + \rho A v^2$$

$$= \rho g V + \rho g v f_d + \rho A v^2$$

$$= \rho(gV + g v f_d + A v^2)$$

Where ρ=Density Of Air

V=Volume Of Ornithopter

v=Relative Velocity

fd= coefficient of drag force

- Condition for safe design:

$\sigma <= s_{yt}/n$

s_{yt} = yield strenth of material

n= factor of saftey

$f/A <= s_{yt}/n$

f= Total Force

A= Area of Ornithopter

Conclusion:

- In order to take flight the lift force should be greater than weight force which is not happening here due to following alternate arrangements. Weight is the major constraint here. Due to high weight of flapping wing mechanism the Ornithopter is not able to take flight. Also Balsa wood is used in placed of Carbon Fiber, which is not a replacement. In this case it is used in order to reduce weight only. The motor used here can be replaced by another high torque motor so that it can produce high torque and can produce enough amount of lift force. If all this replacement could be done then Ornithopter might take flight.

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Thank you….