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# Design and Development of a Fixed-wing Micro Aerial Vehicle

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***Abstract***
*The objective of the project is to design, build and fly a miniature aerial vehicle capable of flying and experimenting excellent flying qualities and maneuverability in low Reynolds regime with high endurance. A fixed-wing type micro aerial vehicle using mechatronics approach is thought to achieve the requirements. In order to design the MAV the following terms were considered: high aerodynamic efficiency, low wing loading, and light weight, low altitude operation, high propeller efficiency. Trial and error has been the most effective design tool in many cases, often leading to lengthy and costly design processes. The unavailability of complete analytical methods and the computational expense of numerical methods make an empirically-based design optimization approach a practical alternative. The entire system consists of a ground remote controller-cum-transmitter and an aerial onboard flight control system which consists of a wireless receiver and control hardware for controlling servos and the motor which in turn controls the direction, orientation and thrust of the MAV in flight.*

**Keywords**: MAV, fixed wing, inverse Zimmerman

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## INTRODUCTION

"Micro Air Vehicles (MAVs) are small aircrafts, with a wing span smaller than 1 m and a take-off weight below 1 kg", according to the MAV laboratory of TU Delft, the pioneers in this area of research. Because MAVs are very small-size and low speed, their Reynolds number are very low that results unique aerodynamic conditions. There has been a constant increase in the development of MAVs around the globe. In India, there is a great craze for rotary-winged quadcopters and hence the potential of fixed wing MAVs is unnoticed. Normally fixed wing designs have higher endurance and forward speed compared to the others. [1] Many factors like the size and weight affect the making of an MAV. The necessity of understanding physics of flight for small vehicles has increased research in this area. Although MAVs are very limited in their ability to carry energy and payload onboard, they can be used for various real-world applications ranging from agricultural to search-and-rescue operations.

Although MAVs are very limited in their ability to carry energy and payload onboard, they can be used for various real-world applications ranging from agricultural to search-and-rescue operations. For observing a stationary target, a fixed wing MAV has to remain airborne over the object, thus expending energy for propulsion and reducing operational time. In addition, the aircraft may have to fly at low speed. [3]

  

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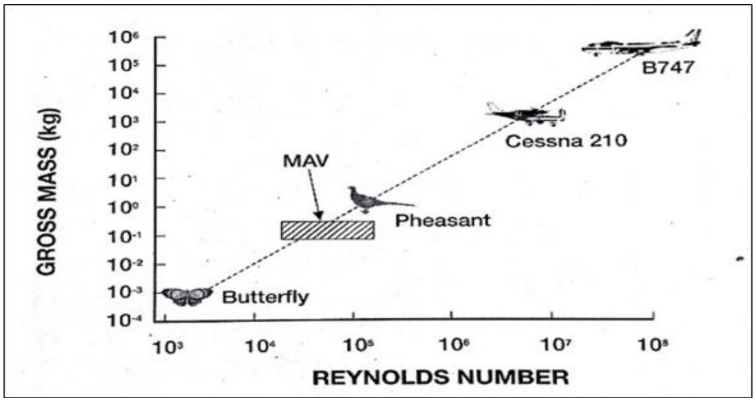


***Fig. 1:*** *Reynolds Number vs. Gross Weight for Various Aerial Vehicles and Birds.* [2]

## WING DESIGN

### Low Speed Aerodynamics

MAVs fall within a Reynolds number (Re) range of 50,000 to 200,000 in which many causes of aerodynamic effects are not fully understood. The research field of low Re aerodynamics is currently an active one, with many universities and corporations working towards a better understanding of the physical processes of this aerodynamic regime. Laminar flow which occurs at low Reynolds numbers makes viscous forces dominant, and is characterized as smooth fluid motion; turbulent flow which occurs at high Reynolds numbers makes inertial forces dominant, which produce chaotic, eddies, vortices and flow instabilities.

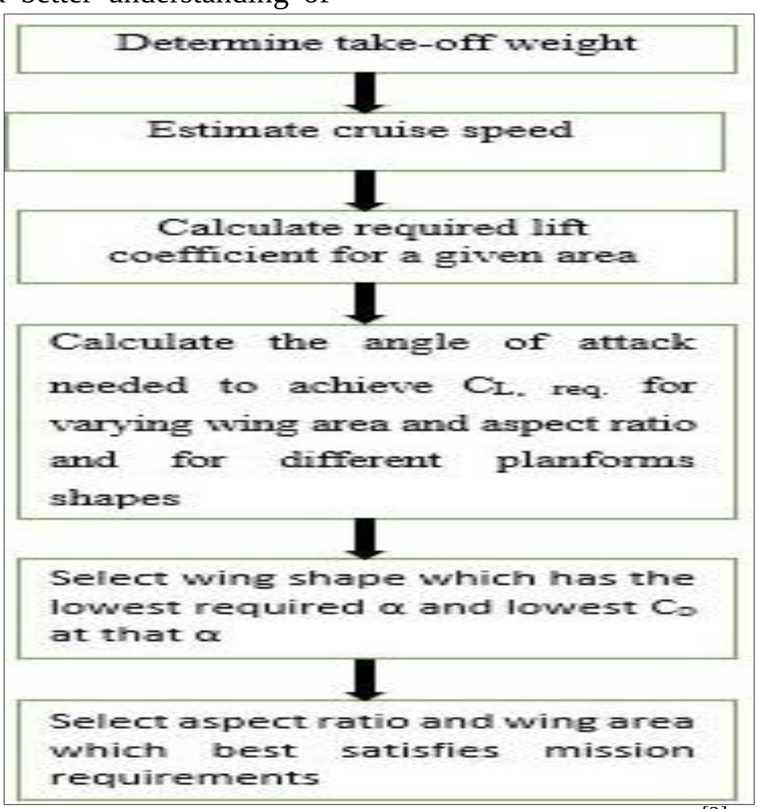


***Fig. 2:*** *Design Procedure for Micro Aerial Vehicle.* [3]

  

## Flying Wing Design

For such a small aircraft, the wing loading is a key factor in determining whether the aircraft will fly. Keeping the weight to a minimum whilst maintain a sufficiently large wing area is vital to control the wing loading. [4] The main advantage of a flying wing design is the low induced drag. The design is essentially a pure wing and therefore has extremely low drag and gives a relatively high CL max. The design also yields good stability when circling which is desirable for loitering and target observation. The structure of a flying wing is relatively simple since there are neither complicated components nor inaccessible spaces. Thus the design should be relatively problem free to construct passing on cost savings. The amount of lift is directly proportional to weight of the MAV. But, the amount of lift generated depends on the area of the wing. As the area increases, the weight is also increased.

## Material Selection

We were studied about various materials available in the market for our MAV balsa wood, foam board, depron, high density foam. Various properties of materials were studied to find the best one. In which we chose depron. It is actually polystyrene (EPS/XPS) plastic. (XPS) means extruded. Depron sheet of thickness 0.006 m, contains density of 33 kg/m3 and it has high tensile stress 0.90 MPa and compressive stress = 0.15 MPa. Depron is four times lighter than balsa. Other woods are twice heavy than balsa. Extruded polystyrene is four times stiffer than balsa.

## Aspect Ratio

The aspect ratio is the ratio of wing span to average wing chord. Aspect ratio of a flying surface largely determines the lift to drag ratio of the surface. Aspect ratio of 1.5 is suited for Inverse Zimmerman based on literature survey.

$$AR = \frac{b^2}{WA}$$

## Inverse Zimmerman Profile

In order to form the Zimmerman and inverse Zimmerman shapes; two half-ellipses are joined at either the quarter chord or three-quarter chord point respectively. The inverse Zimmerman, however, is not as effected by wingtip vortices due to maximum span at the tail Aerodynamic characteristics of the inverse Zimmerman shape is similar to a delta wing. With a delta wing, the wing size normal to the flow increases along the centerline. This allows the control surfaces to be highly effective, even in the presence of strong vortices. The high-pressure air from underneath the wing moves toward the lower pressure on top of the wing.

$$chord = \frac{wingspan}{\pi * AR * 0.25}$$

$$wingArea = \frac{wingspan^2}{AR}$$

$$f_x(t) = \frac{wingspan}{2}\cos(t)$$

$$f_y(t) = \frac{chord}{4}(2\sin(t) + abs(\sin(t)) - 1)$$

Near the tip of the wing, the high-pressure air will slip around to reach the top of the wing. This circulation of air creates around the tip a vortex and also pushes down on the top of the wing, spoiling lift and inducing drag. Formula for generating inverse Zimmerman planform is given below and coordinates were generated using these formulae [5] with the help of MATLAB software and imported to solid works for designing.

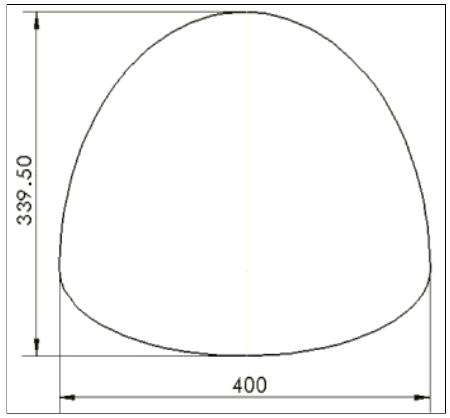


***Fig. 3:*** *Inverse Zimmerman. All dimensions in Figure are in mm.*

**Fuselage**

A rectangular fuselage a main body section of MAV, which is also made of depron was used to protect the electronics, components from damage if incase a fall occurs. Fuselage design should not affect the aerodynamics of MAV. The center of gravity of the aircraft is average location of the weight and it is located inside the fuselage. The fuselage must be designed with enough strength to withstand all opposing forces. A motor mount made of plastic is attached to a box pipe made of carbon fiber. The box pipe is attached firmly to one airframe with the help of thermoplastic adhesive.

These thermoplastic adhesives were available in cylindrical rods and melted using hot electric glue gun. Two elevons are controlled using Servo motors and they are connected with the help of pushrods. They are made of wire or piece of balsa, fiberglass, or plastic, with a clevis fastener at the end. Control horns are mounted on each elevons, where the pushrods are attached. Glass fibre tape is used to connect movable elevons with static structure.

## ELEMENTS OF PROPULSION

The propulsion system is greatly influenced by the characteristic small size of a MAV. The propulsion system must have a high thrust to weight ratio and be capable of high endurance, although in this particular project the endurance was specified as minimum of 15 min.

The motor had to be sufficiently powerful to achieve a rate of climb of at least 2 m/s. Advantages of electric propulsion system was high reliability, reduced noise and vibration, reduced heat emission, high efficiency, high speed control.

**Motor**

Normally BLDC motor windings are inside the can and permanent magnet will be fixed to the rotor part. Since the wires do not move, brushes are not required to transfer the current. Magnetic field is created when different sections of the windings are energized.

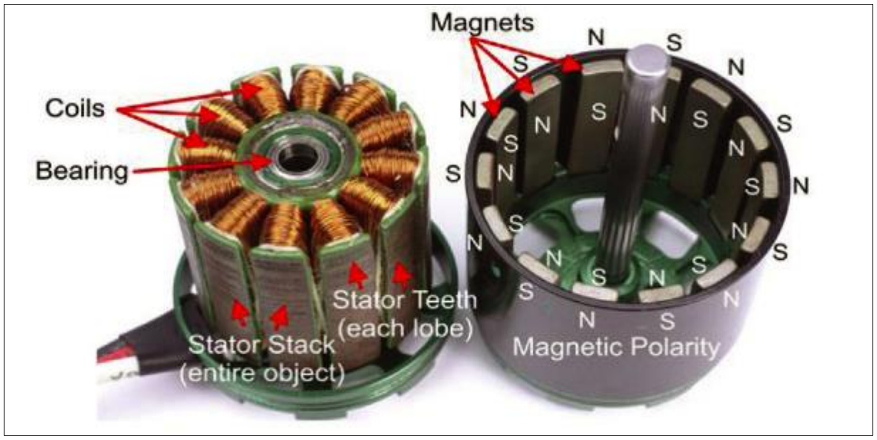


***Fig. 4:*** *Out Runner BLDC Motor.*

Out runner motors have lower KV ratings, so they run at a lower speed with more torque. This could allow you to direct drive larger props without a gearbox. Brushless motors are much more efficient than conventional brushed motors. This efficiency has been measured to be between 75% better than brushed motors of 50–60%. Brushless motors have fewer mechanical parts than brushed motors, so they emit less sound. Fewer moving parts are in mechanical contact than in brushed motors, reducing wear.

***Table 1:*** *Summary of Motor Specifications.*

| **Out Runner Motor** | |
|---|---|
| **Manufacture** | Turnigy D2826-6 |
| **Rpm/V** | 2200 kv |
| **Shaft** | 3.17 mm |
| **Voltage** | 2S~3S(7.4 to11.1 v) |
| **Weight** | 50 g |
| **Watts** | 342 w |
| **Max Current** | 34 A |

**Power Source (Battery)**

The most appropriate power source for micro aerial vehicles is rechargeable batteries. These batteries are capable of delivering power to motors. Comparing five types of rechargeable batteries widely available in the market; Lithium Iron Phosphate (LiFePO4), Lead acid, Nickel cadmium(Ni Cd), Nickel Metal Hydride (NiMH), Lithium polymer (Li Po) in terms of voltage, capacity, safety and energy density. Lithium polymer batteries were selected for MAV due to their small size. Lithium polymers have high energy density compared to all other secondary batteries. So Li Po batteries are very safe for micro aerial vehicles.

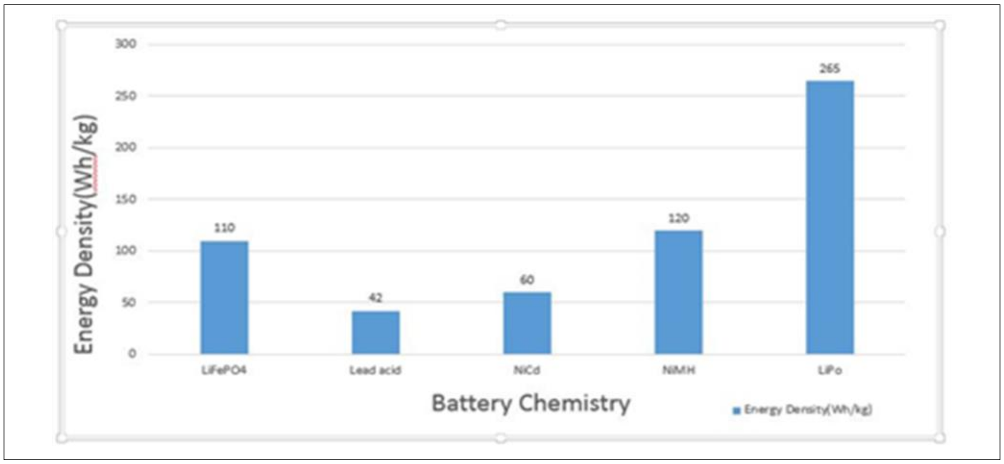


***Fig. 5:*** *Different Battery chemistry vs. Energy Density.*

**Electronic Speed Controller**

Electronic speed controllers (ESC) control the pulses that drive brushless motors. The choice of ESCs depends on reputation, what amperage is needed by the motors. Here we chose a 40 A controller with inbuilt universal battery eliminator circuit (UBEC). It is a facility, which allows the radio receiver and servos to run off the main motor battery (within certain conditions) so that we do not need a separate receiver battery. UBEC works by reducing the motor battery voltage to down to the 5 V needed by the receiver. Maximum amperage of an ESC is greater than motor/propeller combination amperage. If the amperage rating is not high enough, it could overheat and die.

***Table 2:*** *Summary of Electronic Speed Controller Specifications.*

| **Manufacture** | **Turnigy** |
|---|---|
| **Constant Current** | 40 A |
| **Burst Current** | 60 A |
| **Battery** | 2-6S Lithium polymer |
| **BEC** | 5.5 v/4 A |
| **Motor Type** | Sensor less Brushless |
| **Size** | 45x30x17 mm |

**Propeller**

Propeller used for converting motor power into thrust by accelerating large amount of air to high velocity. Pitch is the distance that the propeller “cuts” through the air in a single rotation without slippage. To achieve pitch, the propeller blades are angled to move air to create thrust. The angle of the blade determines its pitch. When they have a higher angle of attack they create more lift. In the case of propellers, a higher angle of attack (pitch) at a given rpm will create greater thrust. A 7×4 inch pitch propeller would move forward 0.1016 m in one revolution.

 

$$F = 1.225\frac{\pi d^2}{4}\left[\left(\text{RPM propeller} \times \text{pitch} \times \frac{1}{60}\text{min}\right)^2 - \left(\text{RPM propeller} \times \text{pitch} \times \frac{1}{60}\right)\text{Vo}\right]\left(\frac{d}{\text{pitch} \times 129}\right)^{1.5}$$

Propeller we chose is 0.1016 m pitch and diameter is 0.1778 m, at 70% of throttle i.e. around 17000 rpm motor able to generate thrust of 0.8 kg. Thrust vs. aircraft speed graph is plotted based on the formula given above.

## Autopilot Integration

In fixed-wing aircraft, there are three critical flight dynamic parameters. These parameters occur in three dimensions as angles of rotation about the vehicle's center of mass. These angles are known as roll, pitch, and yaw. This is used for increasing stability of MAV.

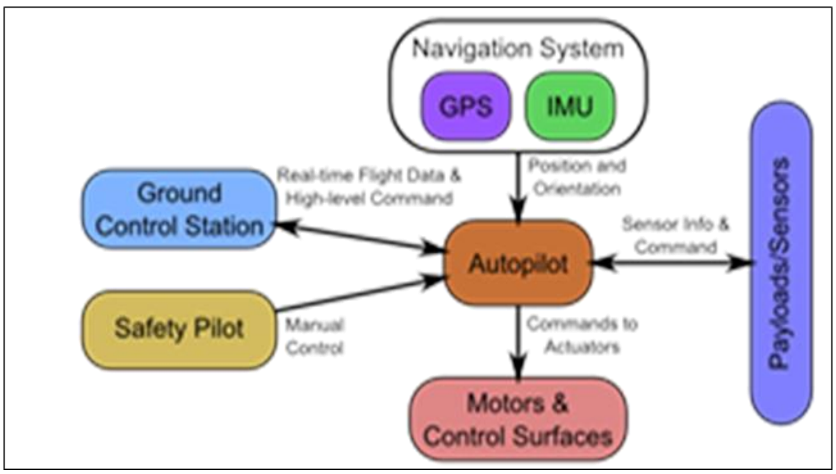


***Fig. 6:*** *Autopilot Integration.*

Autopilot is the combination of inertial measurement unit (IMU), attitude and heading reference system (AHRS) and micro processing unit (MPU). IMU consist of micro-electro-mechanical systems (MEMS) sensors delivers only sensor data as a voltage values.

AHRS gets voltage values from IMU and it solves to give values in terms of angle height etc. Microprocessor in autopilot gives PWM signal to actuate servo motors in order to increase stability.

## CONCLUSION

Only information from database has been utilized in design. Computational formulae were only used for wing profile generation and not analyzed. Further scope is to use computational formulae and wind tunnel is used for analysis of wing performance and development of efficient power plant.

## FUTURE SCOPE

Filtering and control algorithm for MAV's to be employed using custom hardware for greater stability and control. Utilization of more non-conventional methods for wing fabrication is made next level.

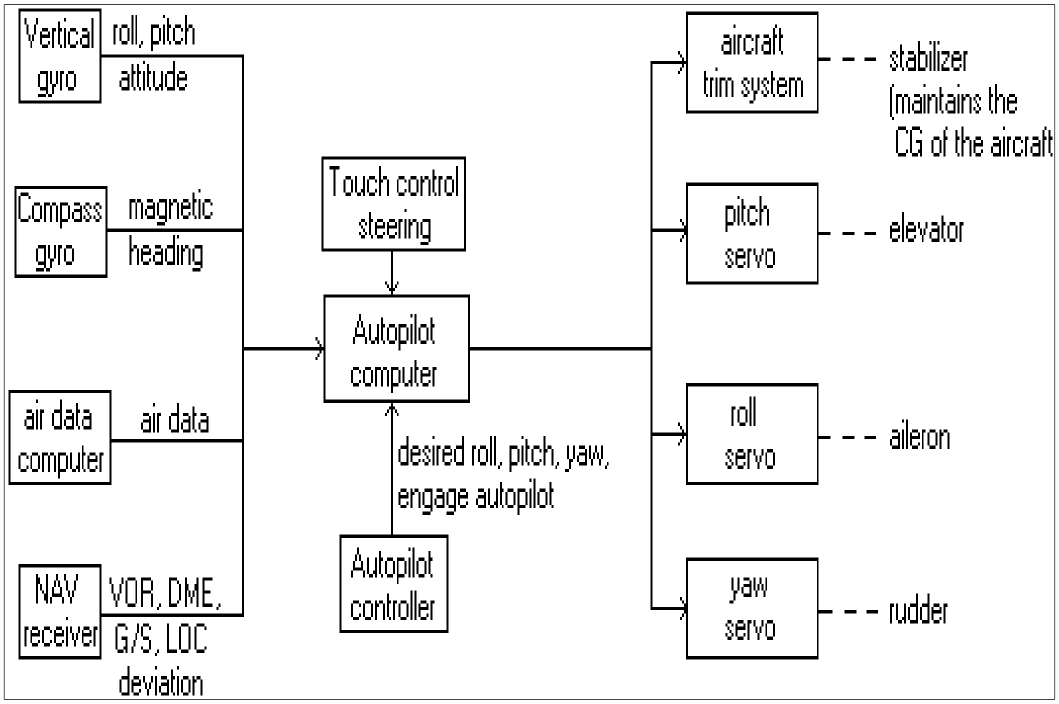


***Fig. 7:*** *Autopilot Architecture.*

## SPECIFICATIONS

| **Planform** | **Inverse Zimmerman** |
|---|---|
| **Size** | Fits in 500 mm Sphere |
| **Wing span** | 0.04 m |
| **Aspect ratio** | 1.5 |
| **Chord length** | 0.0395 m |

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