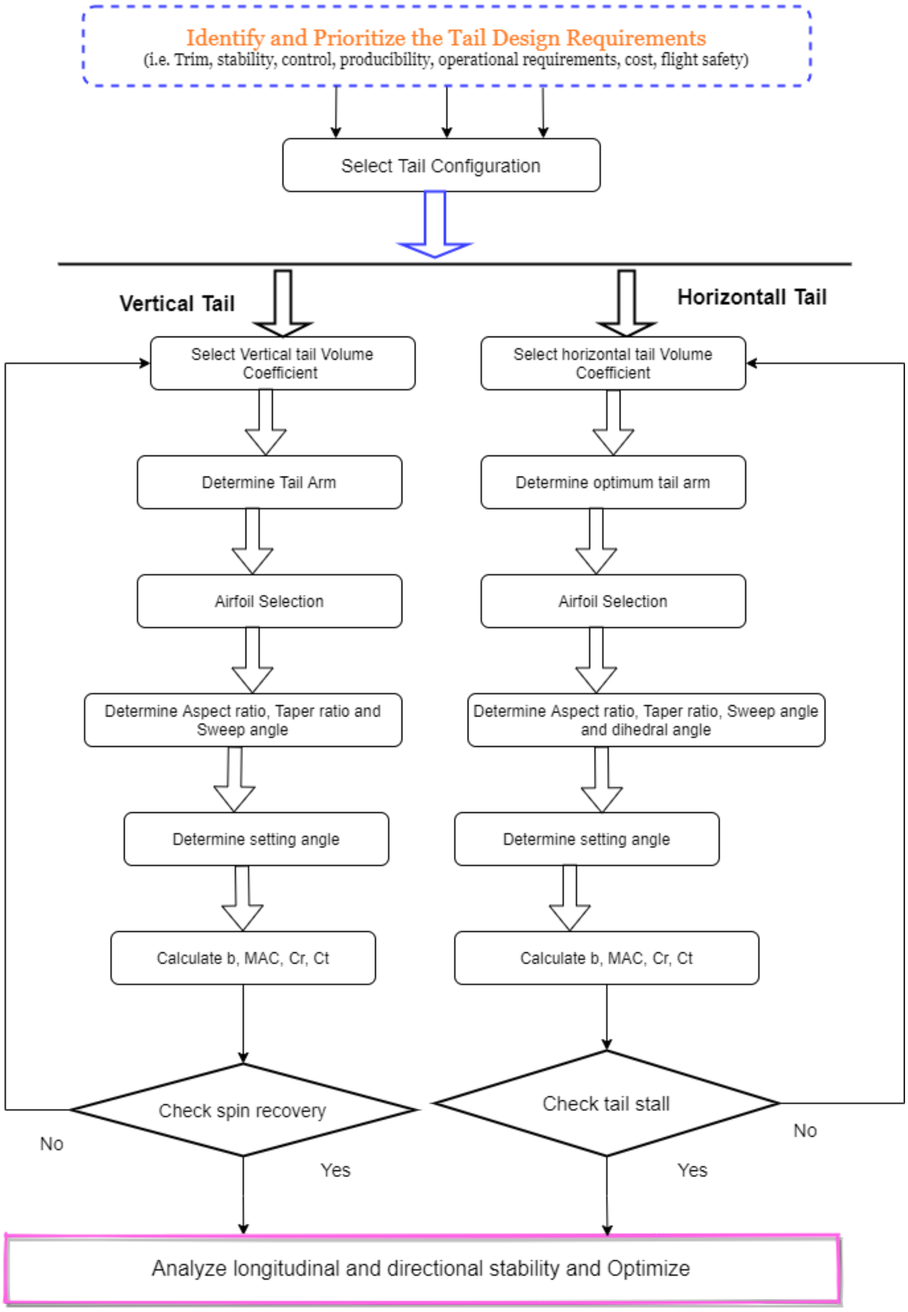
FUSELAGE

- When designing the fuselage, the two main parts to take into consideration are the structural strength and the weight.
- Generally, the sole purpose of the fuselage in this project is to hold the electronics and the cargo.
- The components consist of the ESC, batteries, cables and other electronic components for the flight system and navigation that will be added in the future, while the cargo consists of the three naiads.
- The fuselage itself will consist of a rectangular cube with rounded edges to smooth out the distribution of all forces acting on it, much like why airplane windows have rounded edges to even out the pressure.
- Earlier these suggested a fuselage with the dimensions $2600 * 800 * 410$ mm, and the only difference necessary will be a change to its length, which will be covered bellow.
- The UAV should have the possibility to land on water, a shape mimicking a general raft is to prefer, which has a flat bottom.
- This UAV is unable to completely obtain this bottom due to it having to lift the Naiads from there.
- However, with the current design, a suggestion for a bottom can be designed.

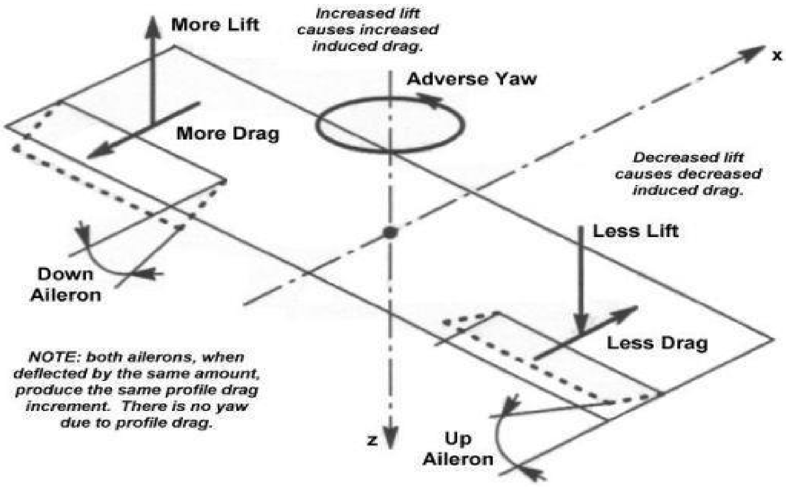
- The two competitors are Aluminum alloys and Carbon Fiber. 2024-T3 is



widely used in aircraft parts which are exposed to high tension, like wing terms of all interesting material data.

WING

- The wing will have to be able to lift the whole UAV while gliding.It will be mounted on the top of the fuselage to ease the use of the tilt-wing design by using one solid structure instead of one wing on each side.
- By having the wing on the top, it also naturally evades as much debris whipped up from the motors as possible, potentially resulting in FOD. The structure of the wing will consist of Form-giving ribs and nose ribs.
- Longitudinal spars to pick up the bending forces.
- Skin to help carry the load during the vertical flight.
- Ailerons for maneuvering. The ribs will take the form of the chosen airfoil which was RG15. It will mostly be used to keep the shape of the airfoil and strengthen the structure when going from vertical mode to horizontal.
- Because of its relative complex design, carbon fiber probably isn't a practical solution. Instead, the initial material chosen will be 2024-T3 with the reservation of a change if a good alternative is found.



Fuselage Design

- The fuselage will hold the batteries, the different components as well as the Naiads. Because it has to land on the water, certain thought needs to be put into design and material.
- The structure will consist of carbon fiber braided square tubes which are pre-made from DragonPlate. They will have an inner dimension of 1" x 2" and a thickness of 0,05".
- Putting them together will be made with gussets made from carbon fiber laminate.
- This will give the skeleton of the UAV a size of 1980 x 1200 x 410 mm, with a weight of 6,31 kg plus the total weight of the gussets (0,14 kilograms).
- The nose and back are identical and consists of a pyramid structure, 410 millimeters in height to make the UAV behave like a raft while in water, strongly improving its buoyancy but keeping most of the aerodynamic advantages.
- The skin will, like the wing consist of 3k Twill Weave carbon fiber prepreg.
- The main difference will be in its thickness, being halved to 0,75 millimeters. Being both, strong, light and water resistant, it makes for a great win-win situation for this project.

Material Selection

Considering the_weight constraint (UAV MICRO UAS with take-off weight<2kg, payload capacity=200gm) and sustainability of the proposed model in specified environment conditions, materials are chosen accordingly.

- **FORMERS:** They are the basic structural members and will be responsible for the structure's stability. Gray Cast Iron was chosen for the formers because of its high strength properties. This provides extra strength to withstand the stresses and pressure at given operating condition
- **BODY**: The body constitutes of the outer shell of the monocoque structure, the wings and the tails. This was made up of carbon fibre (Hexcel AS4C) for providing structural strength as well as to minimise the weight of the UAV.
- **UAV's PROPELLER**: Generally, the propulsive system of a multi-rotor UAV is focally depended upon its propeller.

1. The endurance is comparatively low in the electric propulsive system based multi-rotor UAVs.
2. The glass and carbon fibres-based propellers are drastically used in the UAVs because of its advanced properties.
3. The stiffness to weight ratio is quite high in the polymer matrix composite, which can able to provide better performance at critical phases such as high forward and vertical speed conditions, high gust load environments, and large endurance applications.

a. **Material Optimization based on FSI**: FSI (Fluid Structure Interaction) is a kind of integrating and advanced methodology, which is used to couple data between two different working environments.

i. The fundamental objective of this work is to select the best composite material based on rotodynamic com structural effects.

b. **CFD (Computational Fluid Dynamics)**: The first and foremost data of this work is aerodynamic pressure acting on the propeller due to its rotational, which is executed with help of the CFD tool, i.e., ANSYS Fluent. (Analysis System)

1) The average speed of the civilian UAVs is flying at the speed of 10 m/s so the same one is used as velocity inlet for this fluid analysis.
2) Thus, the aerodynamic fluid density does not vary and thereby the pressure plays a vital role in the fluid analysis so the pressure-based solver is implemented.

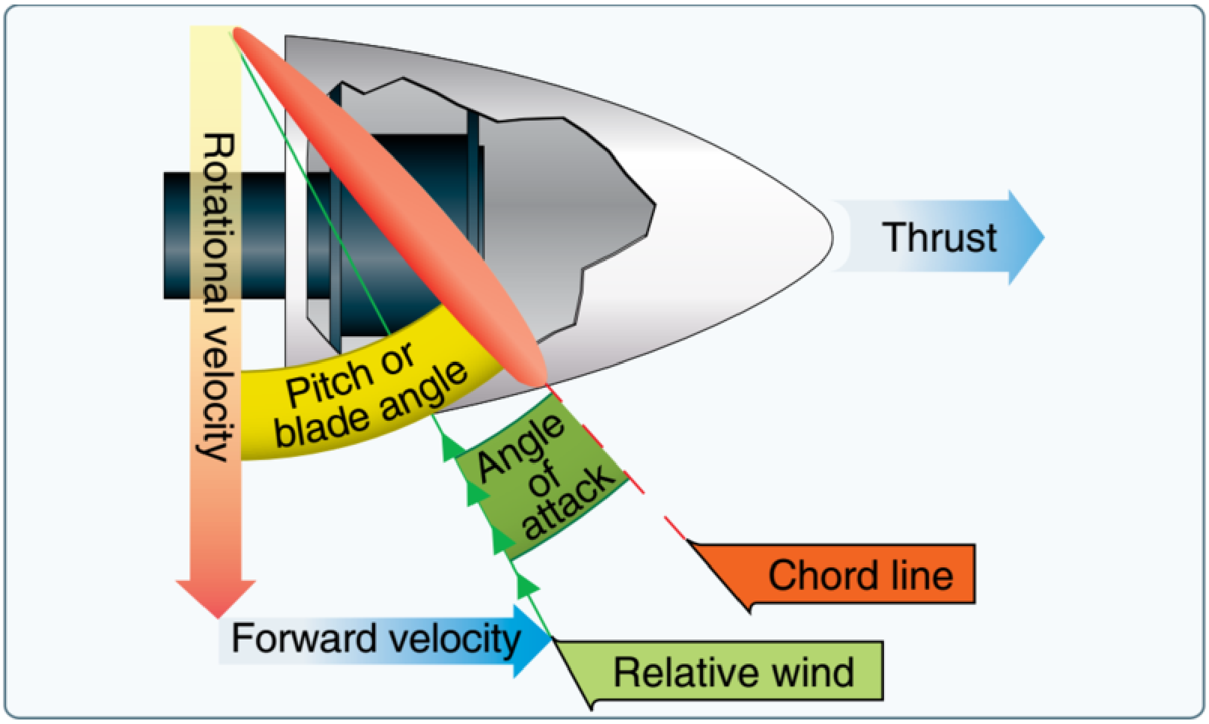
3) Because of the critical work nature of the propeller, the turbulent flow is used at an acceptable rate.

Aspect Ratio (AR): It is the ratio of the square of wingspan to wing area.
The physical significance is that the greater the aspect ratio, the longer and narrower are the wings and is better for cruising and lifting.

Motor considerations

The motor of a multirotor drone is responsible for generating thrust. To achieve flight, the motors should produce around 50% more thrust than the weight of the UAV. This will help the drone fly in windy conditions and make steep turns.

There are two types of motors to choose from, brushed and brushless. Brushless motors offer more power and are suitable for heavier and larger drones.



Propellers can either be designed to spin clockwise or counterclockwise. In a quadcopter, two propellers spin counterclockwise and the other two spin clockwise. Otherwise, the quadcopter will yaw on itself and be uncontrollable. Quadcopters can be modelled as rigid bodies with six degrees of freedom.

The thrust generated by a propeller is directly related to the rotational speeds (revolutions per minute), air density, rotor diameter, shape, and rotor area, as well as its pitch.

Propeller design considerations

A multi-rotor drone is an unmanned aircraft (UAV) that consists of multiple propellers that rotate around a central mast. There is a wide range of setups: three rotors, four rotors, six rotors, and eight rotors. There are also more unusual setups like 12 or 16 rotors. Of these, quadcopters with four rotos are one of the more popular setups.

1) Number of blades

Adding more blades means that there is more thrust being produced. However, each blade must travel through the wake of the one that came before it. That's why there is a limit to how many blades can be used in propeller design.

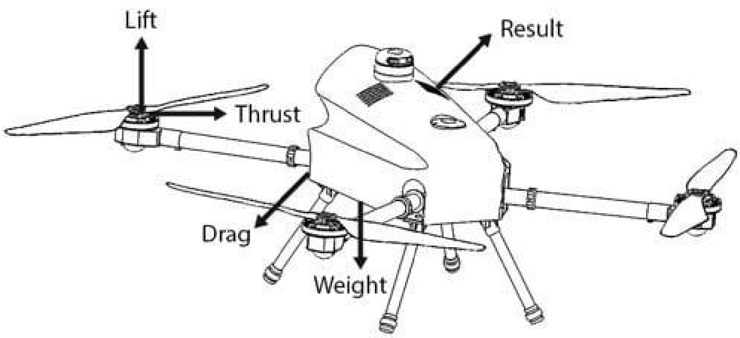
2) Diameter
Smaller diameters translate to less inertia and are easier to speed up and slow down, aiding in maneuverability. Drones with propellers of smaller diameters are typically used for acrobatic flight and racing; they are coupled with motors with high Kv ratings. Larger diameters are coupled with motors with low Kv ratings and can be used for greater payloads.

Larger propellers have more contact with the air and directly impacts flight efficiency. When hovering, larger propellers offer greater stability while smaller propellers are more responsive.

3) Pitch
This is the displacement per single revolution of the propeller. Lower pitch translates to higher torque and lower turbulence, which results in decreased power requirements from the motor. As a result, propellers with lower pitch values increase flight time and allow for heavier payloads. Conversely, propellers with higher pitch move more air per revolution but result in greater turbulence and less torque.

Multirotor drone flight

The resulting aerodynamic force depends on the relative magnitudes of four forces: weight, lift, thrust, and drag. Based on the resulting relative magnitude and direction of these four vectors, the drone will either climb, dive, or bank.



1) Weight
Weight is the force of gravity acting on the object, it is always directed toward the center of the earth. During flight, the weight rotates about the center of gravity. Flying a multirotor drone encompasses two major hurdles. First, the weight of the drone must be overcome by an opposing force. Second, the drone must be controllable in flight. The center of gravity is the point in an aircraft where the combined weight of the aircraft and its cargo is distributed evenly. The center of gravity and the drone's weight plays a major role in drone flight.

2) Lift
Lift is the force exerted on the drone by the air. It is the result of the interaction between the air and the drone. Lift is perpendicular to the flight direction.

The magnitude of the lift depends on the air density and the velocity of the drone. The greater the density of the air, the greater the lift force. The higher the speed, the greater the lift. The shape and size of the drone also contributes to the resulting lift force.

Lift acts through the center of pressure. This is the point at which the lift force and the weight of the drone are in equilibrium. When the drone is at rest, the center of pressure is directly under the center of gravity. When the drone is moving, the center of pressure moves with the drone. The location of the center of pressure changes as the drone changes direction.

Evidently, the performance of the drone is dependent on the position of the aircraft in the air, and, in turn, the distribution of the lift force is also especially important for controlling the aircraft.

3) Drag
The term drag is a generic term used to describe any force resisting the motion of an object through a fluid. It can be produced by a variety of mechanisms.

The drag of a body moving through a fluid is a force, acting in the opposite direction to the motion of the body, and causing a decrease in the velocity of the body.

Like lift, drag acts on the center of pressure and is dependent on the shape and size of the drone as well as the velocity.

For low-velocity flight, drag can be calculated by the below equation:

$$Drag = SkinFrictionDrag + Viscous\,PressureDrag + InviscidDrag$$ **Equation 1.**

Low-velocity drag formula.
In general, drag is calculate with Equation 2.

$$D = C_d \times r \times \frac{V^2}{2} \times A$$

Equation 2. Drag formula.

Drag is a function of the drag coefficient C_d, the drag coefficient is obtained experimentally. In Equation 2, r is density, V is velocity, and A is area.

4) Thrust

Thrust is a mechanical force and is dependent on Newton's third law of motion, where for every force there is an equal and opposite reaction force. The spinning of the blades push air down, there is an equal reaction in the air, creating a force in the opposing direction. Accordingly, the direction of the thrust force will be different depending on the mounting of the propellers.

Detailed Weight Breakdown (CG & Static Margin)

a. The control force F ∝ Sec¯e, i.e., is proportional to the cube of the size of the vehicle; control forces grow rapidly with aircraft size, and large aircraft require powered (or power-assisted) control systems.
b. The location of the C.G. (i.e., the control free static margin) affects only the constant term in the equation.
c. The vehicle weight enters only in the ratio W/S.
d. The effect of trim tab deflection δt is to change the coefficient of the V 2 term, and hence controls the intercept of the curve with the velocity axis.
e. For a given control free static margin (or C.G. position) the control force gradient decreases with increasing flight velocity;
f. At a given trim velocity, the control force gradient decreases as the C.G. is moved aft toward the control free neutral point (i.e., as the static margin is reduced).

S.No	Parameters	Mass(kg)
1.	Empty mass	
2.		
3.		
4.		
5.		
6.		
7.		
8.		

2.

The design focuses on the two main challenges of the landing phase. First, the landing gear needs a trigger so that it can grab the branch quickly. once it is in position. Second, the landing gear needs to be able to provide enough force and have enough friction to keep the quadcopter upright during and after the landing. An initial design is presented of spring-driven, snapping mechanism that allows the landing gear to quickly close around a branch-like object. Grasping is improved with a compliant claw. Flight testing is carried out with the landing gear mounted to an off-the-shelf, radio controlled quadcopter. Based upon results from these tests, an improved design of the snapping mechanism is fabricated and tested on a zip line

II. First Prototype of the Landing Gear

The design goal for this prototype was to demonstrate a working grasp and release mechanism.

A. Snapping Claw Mechanism

In order to address the two primary design requirements, a ‘snapping claw’ mechanism has been designed and fabricated; see CAD images in Figures 1 and 2 and photos in Figure 3. A spring pushes the claw closed, providing the force necessary to grab the branch during landing and keep the aircraft upright while it is perching. During flight, a pin in a slot holds the claw open. When the inside of the claw contacts the branch, a trigger releases the pin and the claw snaps closed. When

B. Compliant Claws

In order to improve the grasping effectiveness, a claw with a compliant structure is incorporated into the landing mechanism. For a perfectly circular branch, there are only two ways to increase the effectiveness of a grasp: by increasing the normal force applied by the mechanism or by increasing the friction between contact surfaces. Using a spring with greater torque accomplishes the goal of increasing the normal force, but has consequences to the weight of the landing gear since there is an approximately linear relationship between spring constant and weight. In addition, a larger spring would need a larger motor to reset the mechanism

C. Zip Line Testing

The performance and capability of the second prototype was tested on a zip line. The mechanism was attached to a 500 gram weight (brass block) and set down the zip line. As shown in Figure 13, the snapping claw was able to grasp both a circular pipe and a square beam.

Experimental setup The experimental setup for the identification of propulsion physical parameters (see in figure 7) consist from the stand, DC power supply control unit and measurement equipment (as shown in figure 8) which enables data acquisition important for subsequent processing and analysis. Control unit enables simple programming and provides required control signals for identification and further analysis

3.1. Sensors To identify the propulsion physical parameters, two sensors where used. Aerodynamic forces where measured with load cell type sensor, while multifunctional logging meter is used to measure angular velocity and power consumption (see in figure 9). 3.1.1. Logging meter. One of the requirements to the design of the experimental setup is simple acquisition and processing of sensor data. Among other things, compact multifunctional and logging meter “PowerLog 6S” is selected because of its simple integration with PC, support for various logging software, 32 bit ARM processor and 12 bit A/D convertor. Also, it provides non-contact optical sensing for propeller revolutions per minute (RPM) measurement with settable blade number and measurement of motor voltage constant.

Take-off: The UAV was placed on the rail pad. The cart starts to move and as the speed increases and reach near the take-off velocity of the aircraft, the UAV starts to lift because of the lift force. Thus the cart is like a removable landing gear of the UAV. The take-off velocity comes out to be 9.42 m/s.[3]

3.2.

We chose a value of AR=7 for *Hillswift* which is quite common for small UAV designs. After modelling, the aspect ratio of the wing reduced to 6.83 because of change in theoretical and practical surface area

Wing Sweep (λ): It is the angle measured between the wing and the fuselage. The aim of providing the sweep was to reduce wave drag which plays role primarily in supersonic planes. For supersonic models, leading edge sweep angle should be considered and for subsonic planes with velocity near the speed of sound, sweep angle of quarter line cord is taken into account.

Since the maximum design velocity of our *Hillswift* is 150 km/h which is quite below the transonic regime. Therefore, there is no aerodynamic requirement for a swept wing.

Taper Ratio: It is defined as the ratio of length of the wing tip chord to the length of the root chord. It affects the lift distribution along the wingspan. It is given by c_t/c_r.

With decrease in taper, the bending moment of the wing decreases due to load distribution. Hence the wing can be made lighter for the same lift of the aircraft. On the other hand, with low taper ratios the region of flow separation generates near the tip of the wing resulting in loss of aileron control of the pilot.

Considering the factors and various available sizes, a taper ratio of 0.5 is used in *Hillswift.*

It is proven that an untwisted elliptical wing planform generates minimum induced drag. By choosing correct values for the parameters like taper ratio, a trapezoidal planform can closely approximate the elliptical lift distribution.

The span efficiency factor e is given by the ratio $1/(1+\delta)$. Figure 2 demonstrates δ vs taper ratio and aspect ratio. Therefore, it is seen that for TR = 0.5 and A=7, δ comes out to be 0.013 giving around 1% more drag than elliptical planform and hence a great choice.

POWER REQUIRED ESTIMATION:

- Power transmission loss: In the propulsion system, the Li-po battery provides the electric power (Pin) to eight DC-brushless motors which transform the electric power to the mechanical power (PM) of the propellers.
- In the transmission process: The Li-po battery may have different power losses, such as Back EMF loss (Pm),
  iron loss (PI), and
  Copper loss (PC).
- Therefore, the propeller mechanical power (PM) is represented as:
  $$PM = M * \omega$$
  where M is torque; ω is rotational speed (rad/s).
- The DC-brushless motors power losses are represented as $Pm = Vm * Im$ where Vm is voltage of Back EMF;
- Im is current of Back EMF. The iron loss (PI) is expressed as:
  $$PI = k * f * B$$
  where k is Steinmetz coefficients; B is the peak magnetic flux density (tesla, T); f is frequency (Hz).
- The copper loss (PC) is expressed as $PC = I\,2 * Rm$ where Rm is resistance of the propulsion system circuit.
- The equation of propulsion system power transmission is then represented as
  $$Pin = PM + Pm + PI + P$$

Conclusion:

- A Multirotor UAV fabricated using carbon strand/epoxy composite material was developed for flight testing.
- A procedure has been presented to estimate the power consumption of the UAV.
- Appropriate equations and testing techniques have been used to estimate the power consumptions of the essential parts of the UAV.
- The power consumptions of the essential parts have been used to predict the total energy consumptions of the UAV for different flight missions.
- Two flight tests have been performed to measure the energy consumptions of the UAV.

- The experimental results have validated the accuracy and feasibility of the proposed energy consumption estimation procedure.
- It has been shown that the proposed procedure can produce good predictions with percentage errors less than 7.4%.
- The proposed procedure may find applications in UAV design and flight mission planning

ENDURANCE CALCULATION:

How long an Unmanned Aerial Vehicle can fly is called **endurance**

The scheme of the calculation for a given time step with a cut-off voltage of 3.2 V

Algorithm of the calculation:

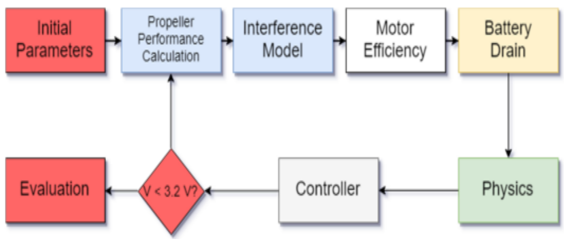
- At first, the initial parameters need to be set (number of propellers, propeller performance input maps, weight of the SUAV, initial rpm, etc.).
- For given parameters, thrust and power coefficient is calculated.
- Then, the thrust of the propeller is adjusted for the obstacles in the downwash (mounting legs of the SUAV).
- After that, the consumed power by the propeller is corrected for motor efficiency at given voltage and PWM.
- If the motor cannot produce the required power, the thrust of the propeller is recalculated for the maximum available power.
- Then, the battery voltage drop is calculated. “Physics” represents the calculation of SUVAT.
- Furthermore, while it is possible to find the required revolutions of the propeller by directly solving this system.
- It is much easier to use controller with multiple PID controllers to stabilize the system.
- Because of the high instability at the beginning of the calculation, which depends on the “quality” of the initial guess of the revolutions.
- The maximum endurance is calculated only after the SUAV stabilization.

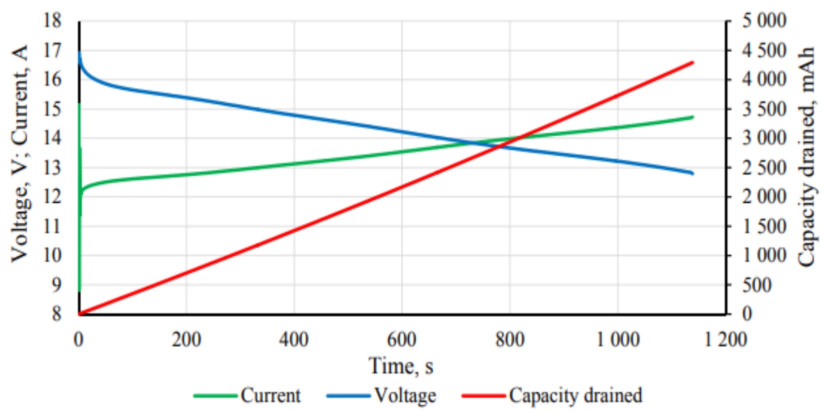
In the first phase, the stabilization can be seen. Then the current in the system proportionally increases, as the voltage decreases.

The overall amount of capacity drained is non-linear and as the battery is drained more and more.

The efficiency of the motor decreases, causing the increase rate of the consumed energy

S.NO	PARAMETERS	VALUES
1	e	
2	K	
3	Endurance	
4	Estimated range	
5	Fuel requirement	





$$Range(miles) = \frac{kV \cdot V \cdot 60 \cdot Pitch}{12 \cdot 5260} \cdot Endurance(hrs)$$

This equation will allow a rough estimation of the UAV's total range. To accurately calculate range the following parameters are needed:

- wing area
- weight
- coefficient of lift of the airfoil used on the aircraft

$$Endurance(hrs) = \frac{BatteryCapacity(Ah)}{Current(Amps)}$$