E-Bird Technology

Introductory Manual for Managers and Biologists

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(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार के अन्तर्गत सांविधिक निकाय)
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Foreword

Tiger conservation is an ecological imperative and national commitment. Given the complexity involved in management of tiger populations, it brings many challenges that need to be addressed. However, being cryptic and elusive, the study of the tiger has always been difficult. Technology has helped overcome this issue to a certain extent. Beginning with radio telemetry systems, camera trapping and recently with M-STrIPES, the National Tiger Conservation Authority (NTCA) in collaboration with the Wildlife Institute of India (WII) is integrating these options. In line with international developments, NTCA and WII have looked at Un-manned Aerial Vehicles as an important option and have made pioneering efforts in implementing a project involving this technology. Unmanned aerial vehicles or UAVs in short—more familiarly also known as drones—are quickly becoming a key equipment for wildlife researchers and managers across the world. Their use has potential to revolutionize the field if they prove capable of improving data quality or the ease with which data are collected beyond traditional methods. We hope that this project would achieve the intended goal of integrating this technology for effective monitoring and management of tiger reserves by playing a supportive role. This manual is a step in the direction of building national capacity for adopting this technology. I wish the Team involved in the project all the best and success towards integrating this sophisticated technology as an integral part of tiger conservation and management.

Date: 19 January, 2018

[Dr. Debabrata Swain]
Member Secretary, National Tiger Conservation Authority

Preface

The field of wildlife research and management greatly benefits from technological innovations, not only to overcome the many challenges of understanding and monitoring wild, free-ranging species and their habitats, but also to enhance the inputs and outputs of conservation research. The most popular recent development has been the use of drones in forest and wildlife applications, wherein such technology is contributing towards sophistication and effectiveness in dealing with pressing wildlife management issues.

'Drone' is a popular term for any self-propelled aircraft that does not have a pilot onboard. In technical terms, drones are also known as unmanned aerial vehicles (UAVs), unmanned aerial/aircraft systems (UASs, while including ground-based elements to the system) or remotely piloted aircraft systems (RPAS). Drones appear to offer a flexible, accurate and affordable solution to many challenges in nature conservation including monitoring and law enforcement.

The last decade has seen the gradual adoption of drones for use in conservation. The usage of drones in recent times can be broadly divided into two categories: research applications and direct conservation applications. Within the research category, drones have been widely used for habitat mapping, wildlife population estimation and monitoring of other biological features and such applications of drones have been providing data that is potentially valuable for conservation. Drones are considered to be particularly useful with respect to direct conservation applications to rapidly monitor and assess vast areas with inaccessible or difficult terrains that are very difficult to access from the ground instantaneously. Drone-based monitoring is very beneficial when used in combination with modeling approaches to predict spatial and temporal patterns of illegal activities. Drones used for conservation purposes have included both fixed and rotary-wing devices, and have tended to be fairly small, weighing less than 10 kg in total.

Wildlife Institute of India and National Conservation Authority have always been at the forefront of conservation efforts and this includes embracing and translating into action efforts involving advanced technology to support research and conservation. It all began as a pilot experiment in collaboration with Conservation Drones and World Wildlife Fund-International in the year 2013 when a test flight was carried out in Kaziranga Tiger Reserve for the first time in the country. This further fueled the interest and development of a large-scale strategy to incorporate drone technology into tiger conservation. The E-bird Technology Project was subsequently conceived as a new initiative, collaboratively by Wildlife Institute of India and National Tiger Conservation Authority, in order to (1) under take need and feasibility analyses for integration of drone technology in tiger reserves, (2) map locations of poaching and conflict prone areas, which would serve as a basis for drone implementation, (3) experiment and implement specialized drone units in a phased manner and (4) build capacity of frontline staff for integration of drone technology as a part of regular management efforts. Spatial data will be collected using drones and a questionnaire survey will be carried out in order to determine poaching risks and potential conflict-prone areas. Low-cost drones (Copter and Plane models) will be customized for training of project personnel and frontline staff. A Technology Laboratory has been established at Wildlife Institute of India to customize specific drone models and these will be used for field trial, data collection and technology transfer to the forest staff of the concerned tiger reserves.

Integrating experiences from across the globe and from this recent initiative (which is first of its kind in India), drone technology is likely to become a mainstay in the field of wildlife research and conservation. This is also likely to open up novel applications for field managers and new ventures for technology groups, which would further enable the spread of technology-based solutions for wildlife management in India.

Efforts of this nature involving sophisticated technology and coordination with various field units require teamwork and lenient support from various institutions and individuals. At the outset, we like to place on record the initial foundation laid by enthusiastic conservationists and leading managers without whom perhaps the birth of E-bird Technology Project would have not taken place. These include Dr. Christy Williams (WWF-International), Dr. Lian Pin Koh, & Mr. Simon Wunderlin (Conservation Drones), Mr. S.P. Yadav and Dr. Rajesh Gopal (National Tiger Conservation Authority), Mr. P.R. Sinha (Wildlife Institute of India), Mr. Ravi Singh (WWF-India) and Mr. N.K. Vasu (Assam Forest Department). Subsequently, the project was immensely supported by Mr. B.S. Bonal & Mr. Sanjay Pathak (National Tiger Conservation Authority), and Dr. V.B. Mathur, Dr. P.K. Mathur & Dr. G.S. Rawat (Wildlife Institute of India). Landscape Ecology and Visualization Laboratory (LEVL) has been supportive since the preliminary stage of the project. Since then, there have been field trials in Panna Tiger Reserve (Madhya Pradesh) and Sathyamangalam Tiger Reserve (Tamil Nadu) and we like to thank Mr. R. Sreenivasa Murthy, Mr. Vivek Jain, Mr. I. Anwardeen and Mr. Arun Lal for extending logistic support. It has always been a great privilege and pleasure to be in the company of well-meaning people who are great source of strength and support and we like to express our gratitude to all those people at the Wildlife Institute of India, National Tiger Conservation Authority and various State Forest Departments.

We hope that this document serves the intended purpose of providing basic insights on drone technology for informed decision making in research and conservation applications, and we hope to update the manual regularly based on the inputs or comments from all users. Please feel free to share your observation and comments for improving it and making it better, like the technology itself.

- E-Bird Technology Team

ABBREVIATIONS

AI	Artificial Intelligence
BLDC	Brushless Direct Current
CG	Center of Gravity
COM	Communication Port
DNN	Deep Neural Network
FLIR	Forward Looking Infrared
FPV	First Person View
GPS	Global Positioning System
GPU	Graphics Processing Unit
IC	Internal Combustion
LAN	Local Area Network
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
LiPo	Lithium Polymer
NDVI	Normalized Difference Vegetation Index
Ni-Cd	Nickel-Cadmium
NiMH	Nickel-Metal Hydride
RADAR	Radio Detection and Ranging
RC	Radio Control
RFID	Radio Frequency Identification Device
RPAV	Remotely Piloted Aerial Vehicle
RPM	Rotations Per Minute
RTL/RTH	Return to Launch/Return to Home
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VTOL	Vertical Take-off and Landing
WP	Way Point/ Waypoint

CONTENTS

1

Introduction

The purpose of this manual is to introduce field managers and biologists to the basics of the technology of Unmanned Aerial Vehicles (UAVs); also known as 'drones' and its application in wildlife management. This manual also outlines the operational procedures and safety precautions involved in using drones, while this provides information for all species and habitats, the focus is on tiger due to its conservation priority.

Background

Tiger (*Panthera tigris*) is amongst the most charismatic wildlife species that drive conservation agenda on account of the ecological functions it plays as a top predator. Its emotional appeal places the species at the center of building larger constituency for conservation actions in general. Accordingly, the tiger population size is showing a positive trend, and a recent estimate places the tiger population in India to be around 2200 tigers[1]. While there are many protected areas that have been designated for the conservation of tiger, much of these are poorly staffed and ill-equipped to deal with poaching which continues to be a major threat, potentially driving the species to extinction. Much of the areas are also inaccessible causing monitoring activities to be highly challenging, specifically during night hours. The problems are only mounting, desperately requiring technological solutions and capacity building inputs. Thus, development and integration of modern technologies such as 'Unmanned Aerial Vehicle' (UAV) along with hands-on capacity building programs will provide significant support in the short as well as long terms. On the other hand, the frontline staff and local communities require inputs to deal with conflict situations and to enhance social capacities.

UAVs, also known as Remotely Piloted Aerial Vehicles (RPAV), have the potential to solve many problems faced by the wildlife research and conservation communities. UAVs are small and medium-sized aircrafts, supported by programmable autopilot and telemetry systems, capable of on board recording and live transmission of information. This technology is becoming powerful across the world and is being utilized in various fields for research as well as for military purposes. UAVs can be involved in surveillance in strategic places and remote areas, night patrolling using thermal cameras, counting and tracking of animals and habitat mapping and monitoring including fire detection.

Nowadays, UAVs are becoming increasingly popular in commercial and private sectors and nearly fifty countries are using them at this time. Many companies are now developing these aircrafts for various applications like toys for kids, tools for aerial photography, counting wildlife, aerial crop survey etc.

Modern drones can be controlled remotely from a ground station or by using onboard computers. They are equipped with complex dynamic automation systems enabling them to follow a pre-programmed flight plan and. Hence, the complete network consisting of a drone and the ground station is termed as Unmanned Aerial System (UAS). In the future, these UAVs will be an integral part of our modern life as the technology will be cheaper and readily accessible for all. This means the scale of research will see an increase in data collection, processing and distribution, producing promising results.

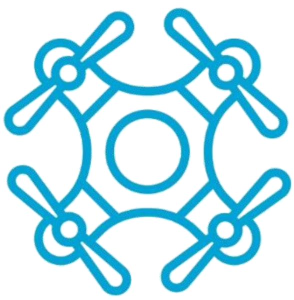
Application of UAVs in Wildlife Conservation and Research

The uptake of UAVs in environmental research has been remarkable. In their short history UAVs are emerging as powerful tools in wildlife ecology and can provide novel remote-sensing data at fine spatial and temporal scales[11]. UAV's has been used in applications as diverse as monitoring breeding success of canopy-nesting birds[8] to surveying elephants[9]. Predictions of the future for UAV technology are based on the perception that the accuracy of data collection, collection efficiency, and cost-effectiveness using UAVs typically exceeds those of traditional methods[10,11,12,13]. In wildlife population monitoring applications it is desirable for population estimations to be accurate; that is to ideally gather an estimate which is close to the actual population number[14]. In wild populations where the true population size is typically not known[15], it is not possible to directly assess the accuracy of any counting method. However, it is possible to assess the precision of a count method, defined as the variance between replicated counts by different counters attempting to count the same sample[14]. Regular precise counts facilitate the detection of small magnitude population fluctuations owing to the lower type II error rate in statistical analysis that comes with comparing measures with smaller variance[16].

Applications of UAS technology are diverse and growing, ranging from sampling airborne microbes to locating wildlife poachers, to providing data on cetacean behavior and body condition. As the technology and regulatory frameworks improve, research applications are diversifying rapidly, and studies incorporating this technology are likely to proliferate in the future. Manned fixed-wing aircrafts and helicopters that are currently used as tools for surveying animals and plants for research, conservation and management purposes may increasingly be replaced by UAVs in numerous applications. While manned aircrafts are also effective in covering large areas they are very expensive, they disturb wildlife, and are the leading cause of work-related deaths among biologists[17,18,19]. Recent technological advances in UAV, combined with increasingly sophisticated remote-sensing equipment, are facilitating ecological research that may be safer, more cost-effective, and less invasive than traditional methods[11].

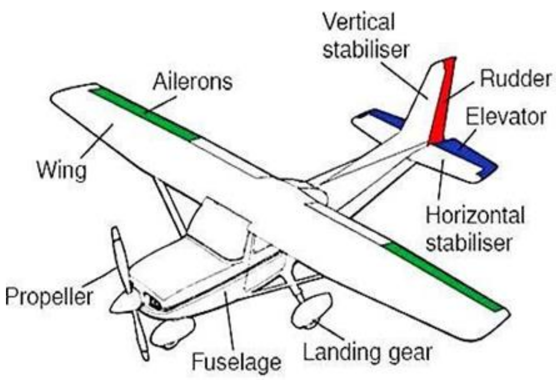
2

Fundamentals of Flight



An airplane is a result of the constant evolution of human intelligence and dedication towards science and its development. Before getting into the physics of flight, it is necessary to know the shape, structure and axis of an airplane. The streamlined body of an aircraft is designed to smoothly cut the air in front and move swiftly through it. With knowledge of the main components of an aircraft, one can visualize their behavior in air.

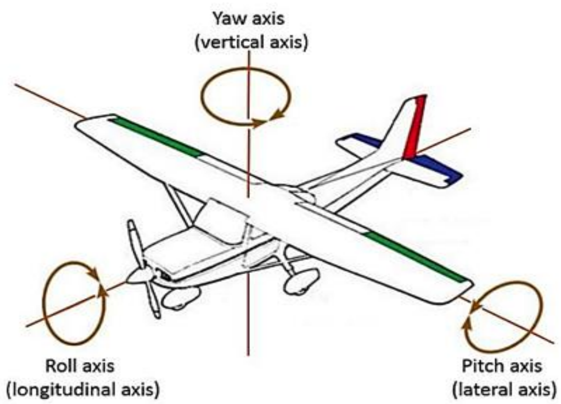
2.1 Aircraft Components



2.1: Main Components of an Airplane

The main component of an airplane is the fuselage (as shown in figure 2.1), which serves as the base to attach other components such as the main wing, landing gear etc. Ailerons are the movable surfaces of the main wing. The tail of the fuselage consists of the horizontal stabilizer, the elevator, the vertical stabilizer and the rudder. The landing gear of an airplane consists of three or more wheels, one of which can be steered to move and turn the airplane on the ground.

2.2 Axis of Control

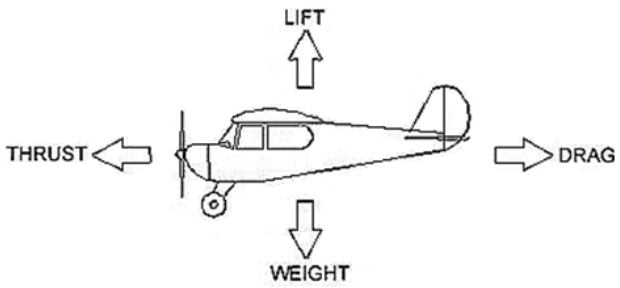


2.2: Axis of Rotation of an Airplane

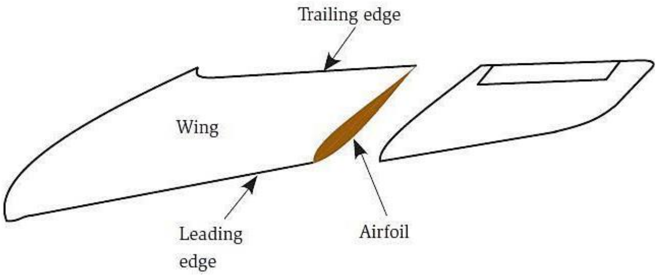
An aircraft can move in three dimensions called roll, pitch and yaw. There are three axes of rotation for an aircraft namely longitudinal axis, lateral axis and vertical axis (as shown in figure 2.2). Rolling can be controlled by the movement of ailerons which rotates the aircraft about the longitudinal axis. Rotation about the lateral axis results in nose-up and nose-down motion of the aircraft, this is controlled by the elevators. Rudder controls the yaw movement of the aircraft about the vertical axis which assists the ailerons in efficient turning of the aircraft.

2.3 Forces Acting on an Aircraft

During flight, various forces act on an aircraft. These forces are exerted on the airplane by the air through which it moves and are called aerodynamic forces (illustrated in figure 2.3). The basic aerodynamic forces acting on an airplane are: lift, weight, thrust and drag.



2.3: Forces Acting on an Aircraft



2.4: Airfoil Shape of Wing

Lift: Lift is the upward force generated by the airfoil shape of the wings (airfoil illustrated in figure 2.4) when it is moved through the air. Although lift may be generated by many external parts of the airplane, the major lift force is produced by three principle airfoils – the main wing, propeller, and horizontal tail surfaces.

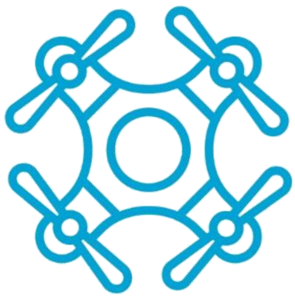
Weight: Weight is the downward force which tends to pull the aircraft vertically towards the center of the Earth. The airplane's center of gravity (CG) is the point at which all the mass of the airplane is considered to be focused. In layman's terms it is the point at which the aircraft would balance in the air.

Thrust: The rotating propeller acts as a moving wing, pushing large mass of air to produce the thrust or forward force that pulls/pushes the aircraft through the air. Therefore, the thrust force should be greater than the drag force to make the aircraft fly.

Drag: Drag is the force which acts in a direction that lies opposite to the thrust force and resists the forward movement of an aircraft through the air. An aircraft is designed to minimize this drag force in order to increase the efficiency and therefore increase its range.

3

Types of UAVs



3.1 Fixed-wing UAV (Airplane)

A fixed-wing UAV is an aircraft which is able to fly using lift generated by the airfoil shape of the wing and the thrust force produced by the propellers. Examples of fixed-wing UAVs are airplanes and delta-wing aircrafts.

3.1: Fixed-wing UAV

A typical fixed-wing UAV resembles a scaled down version of a real aircraft and uses the same principles to fly. These aircrafts sport a light airframe which makes them suitable for long range flights.

3.2 Types of Fixed-wing UAVs

UAVs have different wing shapes which provide different characteristics. Fixed-wing UAVs are basically categorized into conventional and non-conventional wing design.

3.2a Conventional-wing UAV

3.2a: Conventional-wing Aircraft

Conventional aircraft design has all the anatomical similarity to that of a basic aircraft containing elevators, rudders, ailerons, thruster/propeller, and fuselage. Generally, these variants are used for better control of the plane using more control surfaces and this subsequently leads to smoother aerial footage and docile flight pattern.

3.2b Delta-wing UAV

3.2b: Delta-wing Aircraft

These aircrafts have wings that are swept backwards in the shape of a triangle and have minimum control surfaces. The elevators and ailerons are combined to form a control surface called 'elevon'. These elevons can pitch up or down, and also roll the aircraft left or right. This model is very easy to maneuver and responds quickly. The fins at the wing tips are called 'winglets', and they increase the efficiency as well as handling quality of the aircraft.

3.3 Advantages and Disadvantages of Fixed-wing UAVs

Fixed-wing UAVs possess the following advantages:

- Fixed-wing UAVs are capable of long range endurance flights.
- These aircrafts have an aerodynamic design and are very stable during flight.
- These aircrafts are efficient in terms of power consumption, and they usually weigh less.
- Fixed-wing UAVs also require limited maintenance and can be repaired easily.
- And can be landed automatically using the autopilot function.

Fixed-wing UAVs appear to have the following disadvantages:

- Fixed-wing UAVs cannot hover and they lack the vertical take-off and landing (VTOL) feature.
- Fixed-wing UAVs require large unobstructed areas for take-off and landing.
- Although made of 'Expanded Polypropylene' (EPP), the material has limited strength. These aircrafts do crack and bend easily if they experience collision with obstacles.
- These aircrafts have to be hand-launched by a specially choreographed throw.

3.4 Rotary-wing UAV (Multirotor)

A rotary-wing UAV is an aircraft which has rotary blades that spin about a shaft or hub. These rotor blades have very high rotations per minute (rpm) to generate lift. Depending on the applications, these aircrafts may have multiple rotors for enhanced stability and payload capacity.

It is this configuration that enables it to take-off and land vertically (VTOL) which fixed-wing aircrafts are not able to perform. Aircrafts like quadcopters and hexacopters are an ideal choice for monitoring in tight spaces as they have the ability to hover.

3.5 Types of Rotary-wing UAVs (Multirotor)

Depending upon the number of rotors, rotary wing UAVs are of the following types:

3.5a Helicopter

A helicopter has two rotors, main rotor and tail rotor. The main rotor provides the lift and the tail rotor provides yaw control. The main rotor causes a torque which turns the fuselage in a direction opposite to the main rotor. To balance this torque, a counter-torque is provided by the tail rotor.

3.5b Tricopter

A tricopter has three rotors which provide lift force and one of the three rotors (tail rotor) can tilt to provide smooth yaw movement. Tricopters are complex when compared to quadcopters as they need a tilt mechanism to control yaw moment.

3.5c Quadcopter

A Quadcopter has four rotors which provide lift as well as yaw control. This configuration is very stable during flight. It has the ability to navigate through tight corners and can also fly in windy weather conditions.

3.5d Hexacopter

An aircraft with six rotors is known as a hexacopter. They have increased stability and higher payload carrying capacity as compared to quadcopters. Another feature of these aircrafts is that they are failsafe i.e. even if one motor fails, it can operate on five motors. They are used for surveying, mapping, real estate photography, crop spraying etc.

3.5e Octocopter

Aircrafts with eight rotors is known as octocopters. These aircrafts are extremely stable even in windy areas. The payload carrying capacity is maximum when compared to all other configurations. These aircrafts are used extensively by cinematographers as they can carry high resolution cinema cameras.

3.6 Advantages and Disadvantages of Rotary-wing UAVs

Rotary-wing UAVs possess the following advantages:

- Rotary-wing UAVs have vertical take-off and landing (VTOL), as well as hovering capabilities.
- These UAVs can lift heavy payloads as compared to fixed-wing UAVs.

- They are extremely stable during flight and are highly portable as compared to fixed-wing UAVs.
- Rotary-wing UAVs are also available in micro sizes and hence has a wider range of usage and application.
- These UAVs require less space to operate as compared to fixed-wing UAVs and are preferred for interactions involving close proximity.
- They can also be equipped with an obstacle avoidance system.

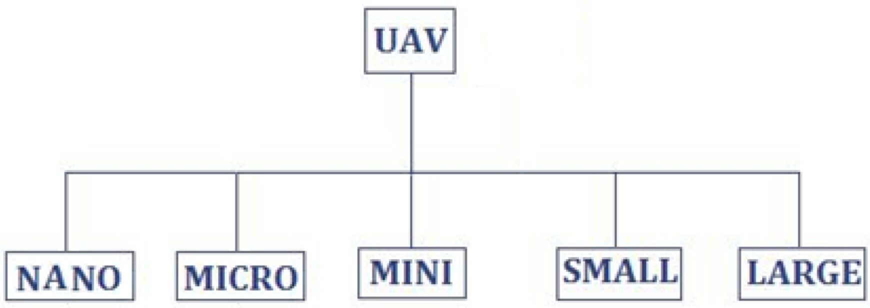
Rotary-wing UAVs appear to have the following disadvantages:

- Rotary-wing UAVs lack the capability to glide with stability.
- These UAVs exhibit less endurance due to the presence of multiple rotors.
- These UAVs will function properly only if they have a robust and vibration-free design.
- Rotary-wing UAVs are noisy and they are also more expensive as compared to fixed-wing UAVs.
- The rotors are vulnerable to damage without proper propeller-guards.
- It is difficult to manage a rotary-wing UAV at higher altitudes due to the presence of thin air in such regions.

4

Classification of UAVs According to Size and Weight

UAV's are used for various purposes, and are categorized according to their size and weight, specific usage, payload capacity and operating range. In November 2017, the Directorate General of Civil Aviation (DGCA) had announced draft regulations on civil use of drones which were classified according to size and weight as mentioned below20.



4.1a Nano UAVs (Weight: less than or equal to 250 grams)

4.1a: Black Hornet (Type-Nano) UAV)

These UAVs are very small in size. They have very less payload capacity (consisting of very small and light cameras) with a limited range. These drones are mostly used for military applications, surveillance and also by the disaster management forces during search and rescue missions for searching within collateral damage.

4.1b Micro UAVs (Weight: greater than 250 grams and less than or equal to 2 kg)

4.1b: RQ-11 Raven (Type-Micro UAV)

These UAVs are slightly larger in size and have higher payload capacity. These are light-weight, hand-launched, portable machines that fly at low speeds and altitudes. These drones are used by military as well as by photographers for their stability and high endurance capabilities.

4.1c Mini UAVs (Weight: greater than 2 kg and less than or equal to 25 kg)

4.1c: Scan Eagle (Type-Mini UAV)

The UAVs of this category are of decent size and are capable of carrying heavier equipment and sensors, they are mostly used for mapping larger area, and for long distance surveillance missions. These drones can operate for longer durations at higher altitudes as compared to micro category UAVs.

4.1d Small UAVs (Weight: greater than 25 kg and less than or equal to 150 kg)

4.1d: RQ-7B Shadow (Type-Small) UAV)

The aircrafts belonging to this category have higher range and endurance as compared to their previously mentioned counterparts. They are mostly used for military applications, aerial surveys, assessment of battle damages, search and rescue, mapping and research activities.

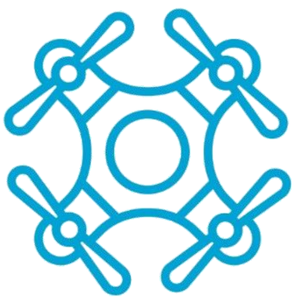
4.1e Large UAVs (Weight: greater than 150 kg)

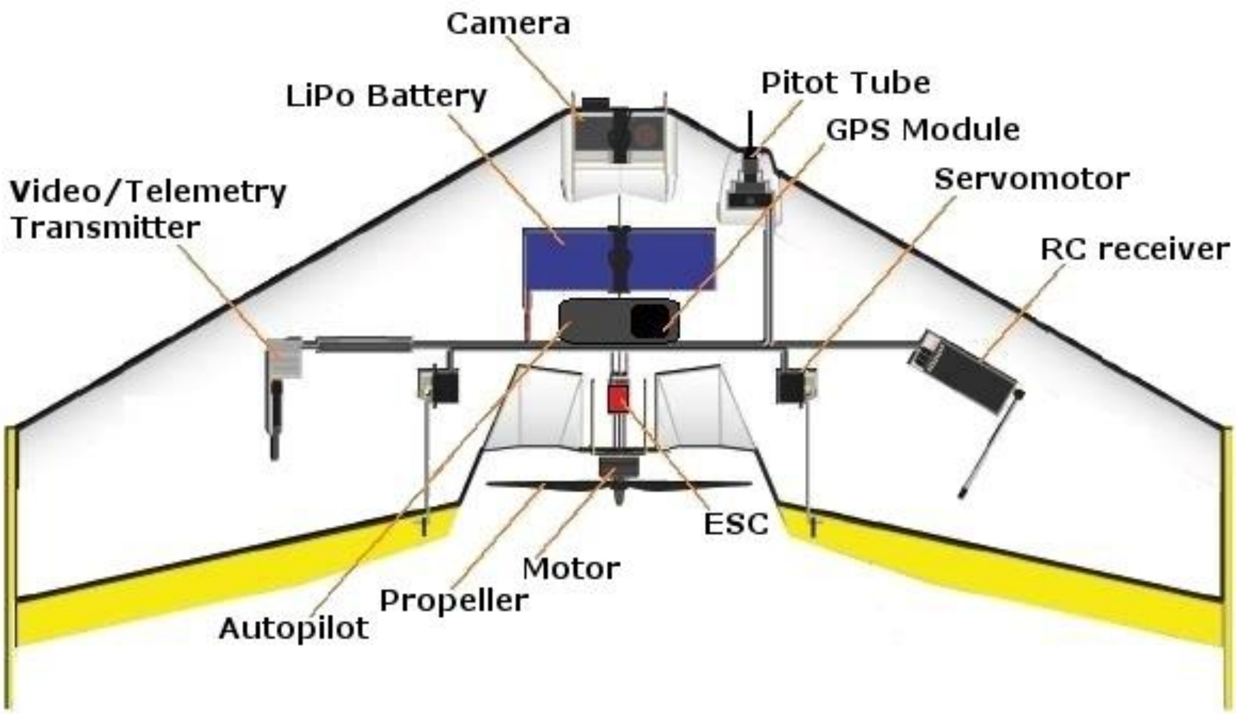
These drones are almost the size of a real aircraft. These drones are limited to military applications for surveillance and assault missions, they can carry very heavy cameras, sensors and RADAR (Radio Detection and Ranging). Some of them are also weaponized with glide bombs and laser guided missiles.

4.1e: Examples of Large UAVs

5

Main Components of an Unmanned Aerial Vehicle (UAV)





Motor: Motors are the propulsion system for drones. A BLDC (brushless direct current) motor is usually used, which has 95% efficiency. It provides the thrust required for an aircraft to move. A propeller or thruster fan is attached to propel air and generate lift.

Propeller/Thruster-fan: The propeller is basically a type of fan, which converts the rotational motion to thrust. A pressure difference is created between the upper and lower surface of a propeller and fluid (air) is accelerated behind the blade. When a propeller is mounted behind the fuselage it is called a 'thruster-fan'.

Servomotor: A servomotor is a specific type of motor that allows precise control over the angular position and velocity of rotation. They are used to move the control surfaces to specific angle like deflecting the ailerons, rudder etc. For radio flying applications, they are also called micro-servos.

Telemetry: Telemetry system is a crucial component which establishes the communication link between the aircraft and the base station using a high power/gain antenna.

Radio Controller (RC): Radio controller is the key to control the aircraft. It contains a joystick configuration, which is programmed to control the ailerons, elevators and the rudder as per the pilot's requirement for manoeuvring the aircraft.

Camera: GoPro or any other camera is usually attached to the front side of the fuselage to capture aerial video/footage/data for analysis and documentation.

LiPo battery: LiPo battery is a crucial part of any drone as it provides power to each component of the plane. LiPo batteries are basically high powered 'Lithium Polymer' batteries containing high discharge rate to power the motor and other electronic parts.

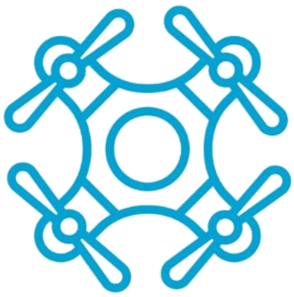
Electronic Speed Controller (ESC): Electronic Speed Controller (ESC) is a device that has a micro-controller, which regulates the speed/ rotations per minute (rpm) of the motor as per the pilot's instructions by regulating the input voltage.

Autopilot: Autopilot is a key part of any drone, which contains an on-board flight computer that in turn helps the drone to navigate and perform the pre-programmed task.

Global Positioning System (GPS) & Compass: The GPS module in many autopilots comes with an inbuilt magnetic compass that helps navigate through a pre-programmed flight plan by making the drone aware of its current heading and location.

6

Battery Storage and Handling



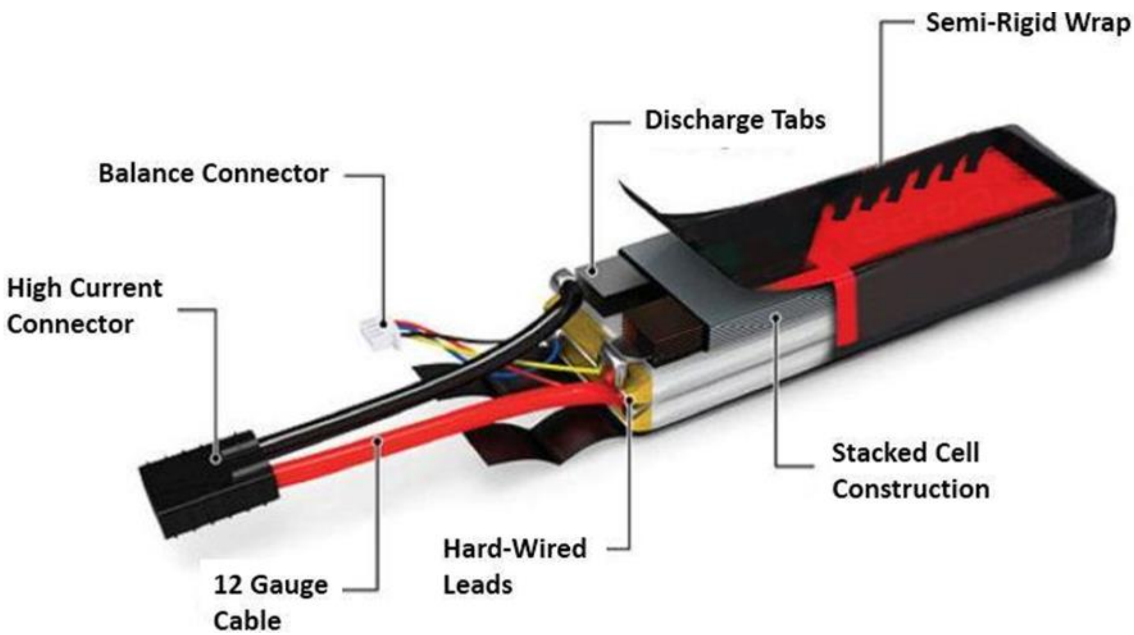
Lithium-Polymer batteries or 'LiPo' batteries, are now the most popular choice for those who want to fly the drones for a longer duration and with higher power. LiPo batteries are becoming ideal for RC planes, helicopters, multirotors and more. There are other options available but these batteries have advantages over other types.

Some of the advantages of LiPo batteries over NiMH or Ni-Cd batteries are:

- These batteries are much lighter in weight and can be easily manufactured in any size or shape.
- They have very high capacity to hold charge and have high discharge rates compared to other types.

  LiPo batteries do have some disadvantages as well. They have a shorter life span and can lead to fire hazard if punctured. However, they provide excellent results when handled with care.

6.1 LiPo Battery Anatomy



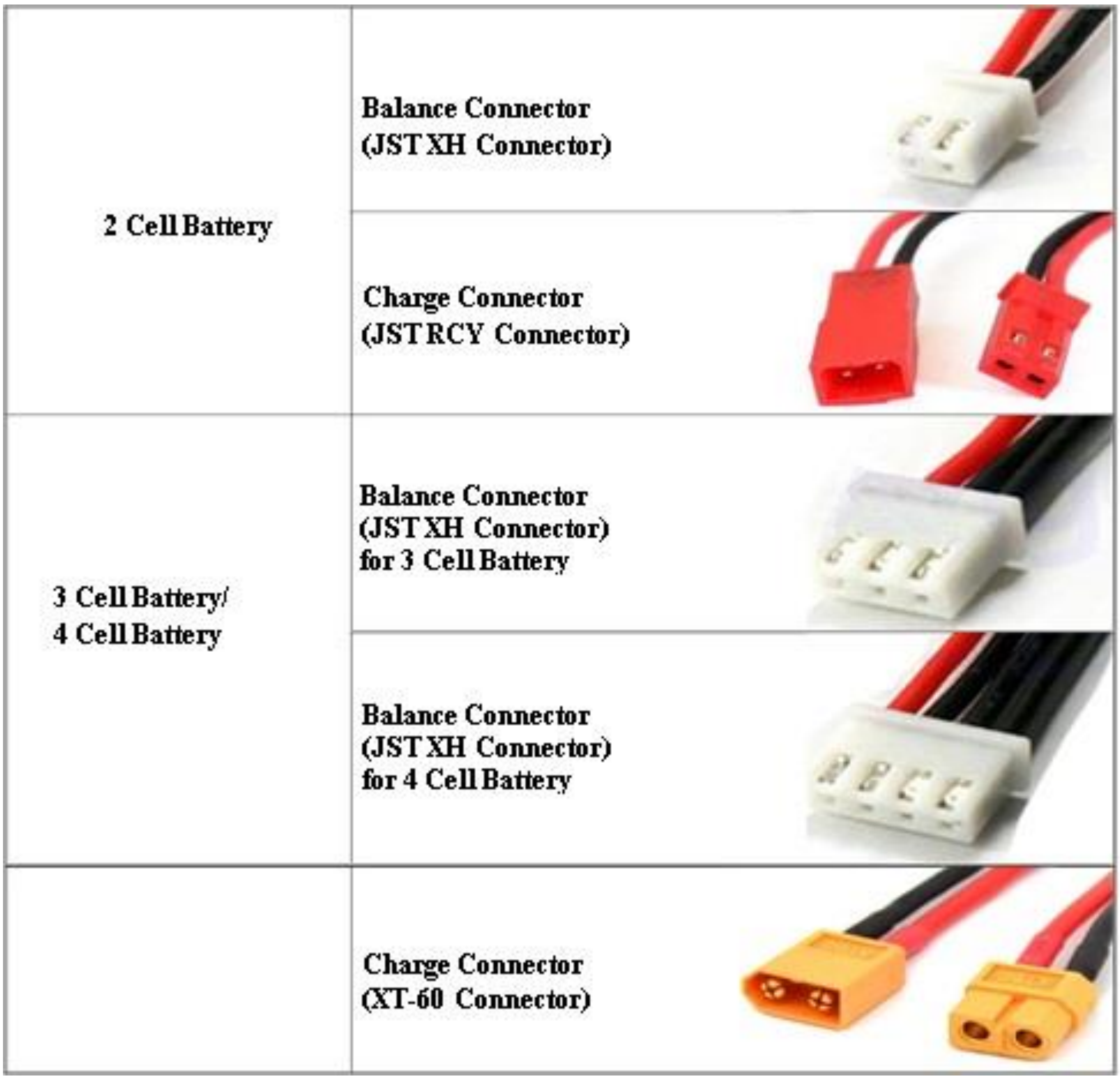
LiPo batteries have simple construction design (as shown in figure 6.1). Cells are hardwired to each other leading to a high current connector and a balance connector. The high current connector is used for charging, discharging as well as supplying power to electronics. The balance connector is used by the charger to maintain the voltage of each cell at the same level.

In addition, there are three main specifications of a LiPo battery:

Voltage: A LiPo cell has a nominal voltage of 3.7V which is called 'half-charged' voltage. The voltage varies depending upon the number of cells in a battery pack. If a battery is labelled as a '2S' battery, it means that 2 cells are connected in a series. Similarly, a 3 cell (3S) battery will have 3 cells connected in series. Hence, the voltage also multiplies, for example, a 2S battery has 7.4V and a 3S battery has 11.1V nominal voltage. When the battery is completely charged, its voltage per cell goes up to 4.2V/cell. This is the maximum voltage a battery cell can pack.

Capacity: The amount of power which a battery can hold is defined as the capacity of the battery. Battery capacity is measured in milliamp hours (mAh). Higher mAh battery means it can supply power for a longer time period. Bigger the capacity, bigger the physical size and weight of the battery.

Discharge Rate: A measure of how fast a battery can discharge safely is known as 'C rating'. Depending upon the load on the aircraft, appropriate C rating battery must be chosen. For most of the applications 20C or 25C battery is fine, but if the requirement is - very high speed or larger motors, around 40C battery pack also can be used. There are different types of LiPo battery connectors depending upon the number of cells, and these have been depicted in figure 6.1a.



6.1a: Types of LiPo Battery Connectors

6.2 Charging and Usage

Charging a battery might sound simple, but when it comes to LiPo batteries, charging must be done safely and carefully. It is always advised to put the battery in a LiPo safe bag for charging purposes.

The equipment required for charging LiPo batteries are depicted below.

6.2a: Balance Charger/Discharger

6.1b: LiPo Safe Bag

6.2c: Banana-plug to JST RCY Charging Cable

6.2d: Banana-plug to XT-60 Charging Cable

6.2e: Banana-plugs connected to Charger

6.2f: Battery Connection with Charging Cable

6.2g: Balance Ports

6.2h: Battery Connected

A balance charger should be preferred instead of a normal charger as it maintains all the cells of the battery at same charge level by charging them individually. Other chargers do not balance the cells.

One should follow these steps to charge the LiPo battery:

1. Connect the red and black banana-plugs of the charging cable into the red and black banana ports of the charger as shown below.
2. Connect the battery's discharge plug to the charging cable.
3. Connect the balance lead into the balance port on the charger.
4. Toggle the charging current by pressing and holding the START/SELECT button. The notification LED indicator switches from 0.5A to 1A, 1A to 1.5A and so on.
5. Ensure that the battery is not overheating while charging, if so, immediately switch off the charger.
6. When all the cells are charged and balanced, charger will make a beeping noise. Make sure to remove the battery from charge without delay.

6.2i: Toggle Charging Current

LiPo batteries have to be handled and maintained properly for efficiency and safety. If handled improperly, they can be extremely hazardous.

To ensure the proper handling and usage of LiPo batteries, follow these guidelines:

Do's

1. LiPo battery must be charged using a proper LiPo battery balance charger/discharger. Balance charger maintains the same voltage across all the cells in the battery.
2. Always keep a Class D fire extinguisher near the battery.
3. Always inspect LiPo packs regularly for any damage.
4. Use LiPo safe bags while charging and storing batteries.

Don'ts

1. Do not use a LiPo battery if it is puffed up. Dispose the battery if it becomes puffy or gets damaged after usage.
2. Do not overcharge a LiPo battery.
3. Do not charge LiPo batteries on wooden table or near flammable objects. Charge them on concrete or ceramic surfaces.
4. Do not leave the battery unattended while charging. If it starts to smoke or catches fire while charging, someone should be present there to handle the situation.
5. LiPo batteries do not work well in cold weather. As the temperature decreases, chemical activity within the battery slows down. In extremely low temperatures like below -10° C (14° F), the battery may fail at any time.
6. Do not discharge the battery below 3.2V per cell to maintain the battery in healthy condition. Discharging the battery below this voltage may cause permanent damage.
7. Do not drain the battery completely, as it will shorten its lifespan.

6.3 Storage

1. Always store your LiPo batteries at room temperature. Keep them away from heat as it reduces the lifespan of the battery and may cause fire hazards.
2. Do not use plastic travel cases to store LiPo batteries for long times as these cases are not fire proof.
3. Use LiPo safe bags to charge/discharge or store the batteries. All the LiPo batteries can undergo internal short circuit at any time.
4. For safe storage, all batteries should be kept at 50%-70% storage.
5. LiPo batteries should not be left unattended for a long period of time.

6. Always pack your LiPo batteries in your carry-on bag and never in your checked baggage when traveling on an airplane.

6.4 Battery Disposal

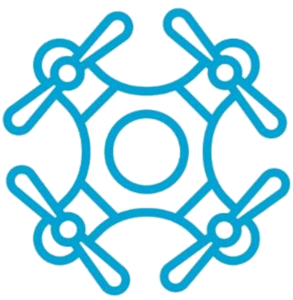
LiPo batteries are safer than NiMH and Ni-Cd batteries but still they must be disposed of carefully. For proper disposal of these batteries, follow these steps:

1. Discharge the battery completely using the discharge feature of the Battery Charger.
2. Add salt in warm water and mix thoroughly, keep adding salt till it stops to dissolve and the solution is saturated.
3. Submerge the battery into the salty water and make sure all the connecting wires are dipped inside the water.
4. Keep the battery submerged for 24 hours.
5. Check voltage of the battery. It must be 0.0V, if it is not, then keep it submerged for another 24 hours.
6. Check voltage of the battery again. If it is 0.0V, then it is safe to dispose.

   For final disposal, batteries should be sent to a chemical waste disposal facility.

7

Flight Preparation/ On-site Procedures



7.1 Safety Precautions

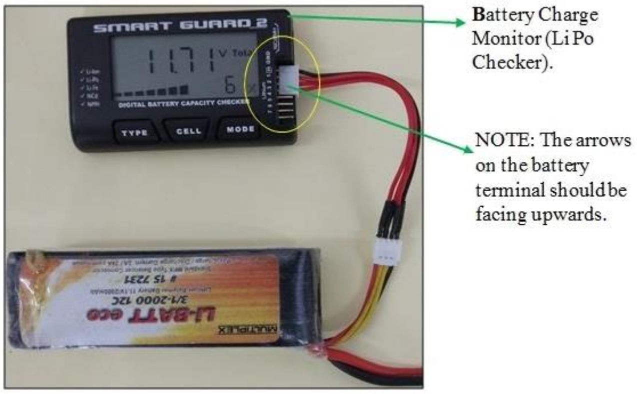
1. Always be aware of rotating propellers.
2. Keep away from fire.
3. Always store the battery in LiPo bags.
4. Prevent equipment from moisture.
5. Do not fly in adverse weather conditions such as in high winds, rains or reduced visibility.

7.2 Preparation for Task/Mission

1. At least two persons are required for the task.
2. Choose the location which is dry and has at least 100 meters of clear space.
3. Inspect equipment for any damage and deploy only fully functional unit.
4. Make sure that you have at least two extra batteries for a single mission.
5. Ground station should have enough battery level for the mission.

7.3 Pre-Flight Checks

1. Ensure that the Battery Charge Level is at least 90% using the battery charge monitor (LiPo Checker).



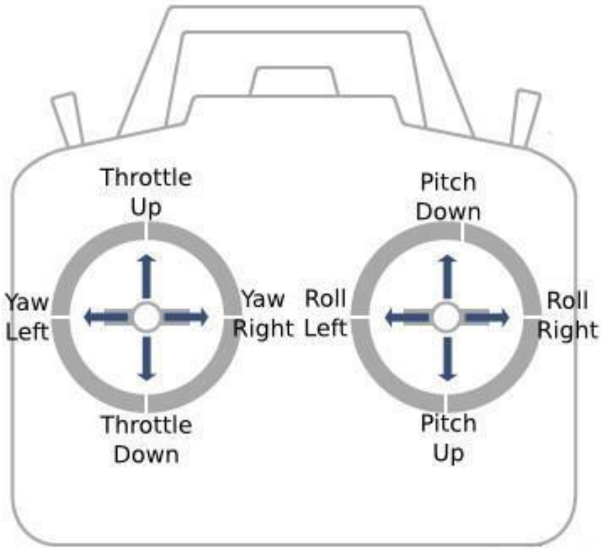
7.3a: Battery Check

2. Check the Camera's functions as depicted in figure 7.3b below.

i.	ii.	iii.	iv.
Insert the Memory Card.	Press and Hold the Mode/Power button until the LED blinks to Switch ON the camera	Check the Battery Level on the display.	Check the mode settings for Date, Time, Still Camera and Video functions.
			

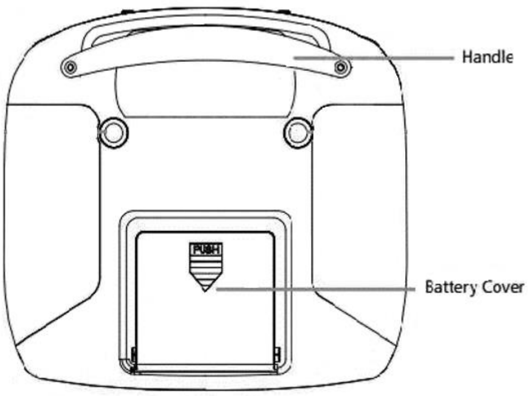
7.3b: Camera Check

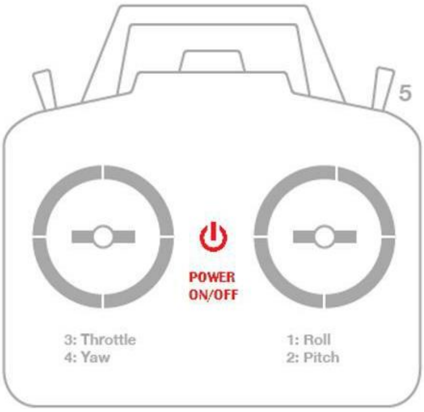
3. Take the Radio Controller (Joystick) of the respective Drone. Follow the steps mentioned in figure 7.3d below.



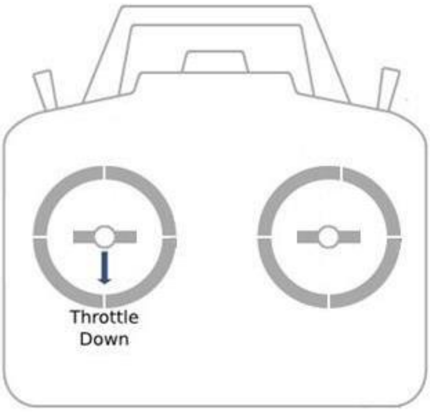
7.3c: Radio Controller / Joystick

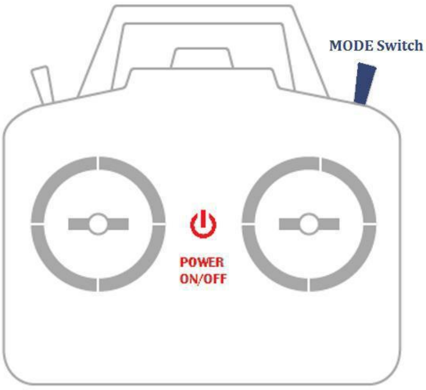
i. Insert the specified number of AAA batteries	ii. Turn the Joystick ON





iii. Push the Throttle stick down	iv. Mode in 3-way switch





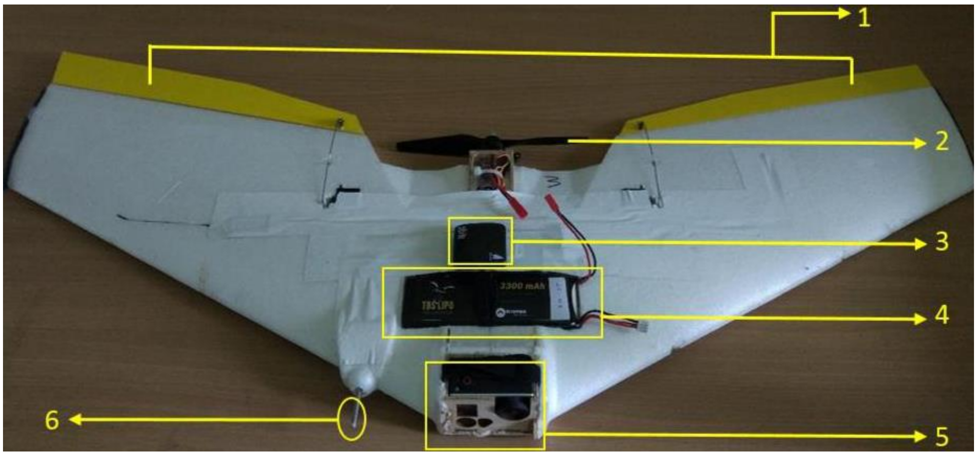
v. Change to the Manual Mode (MNUL) as per the mode switch options given in figure 7.3e below

7.3d: Operating the Radio Controller / Joystick

No.	Modes	Position	Uses
1	Manual Mode (MNUL)	Push to Top	Before switching on the Joystick, always ensure it is in Manual Mode. Manual Mode should be maintained before connecting the Drone to mission planner as well.
2	Autonomous Mode(AUTO)	Push to Mid	Used for flying the Drone in auto mode, with a pre-planned flight path
3	Return to Launch Mode (RTL)	Push to Bottom	In case of emergencies (bad weather, malfunction of drone) RTL is used to recall the drone to the home position where it was launched from.

7.3e: Mode Switch Options

4. Check the Drone for damages to the parts mentioned below.

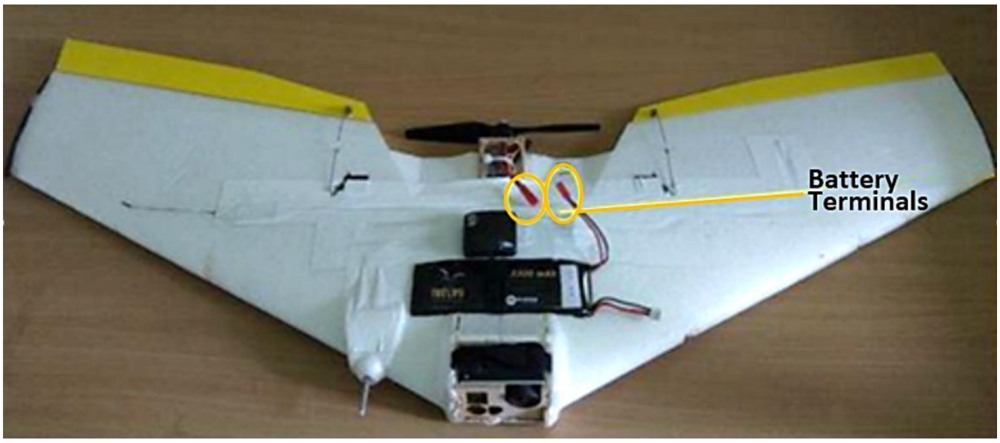


1. Control surfaces	2. Propeller	3. GPS
4. Battery	5. Camera	6. Pitot tube

7.4: Components of UAV

5. Place the drone in an open space to facilitate the GPS; i.e. do not place under a tree or a building.

6. Connect the battery terminals to power ON the drone.

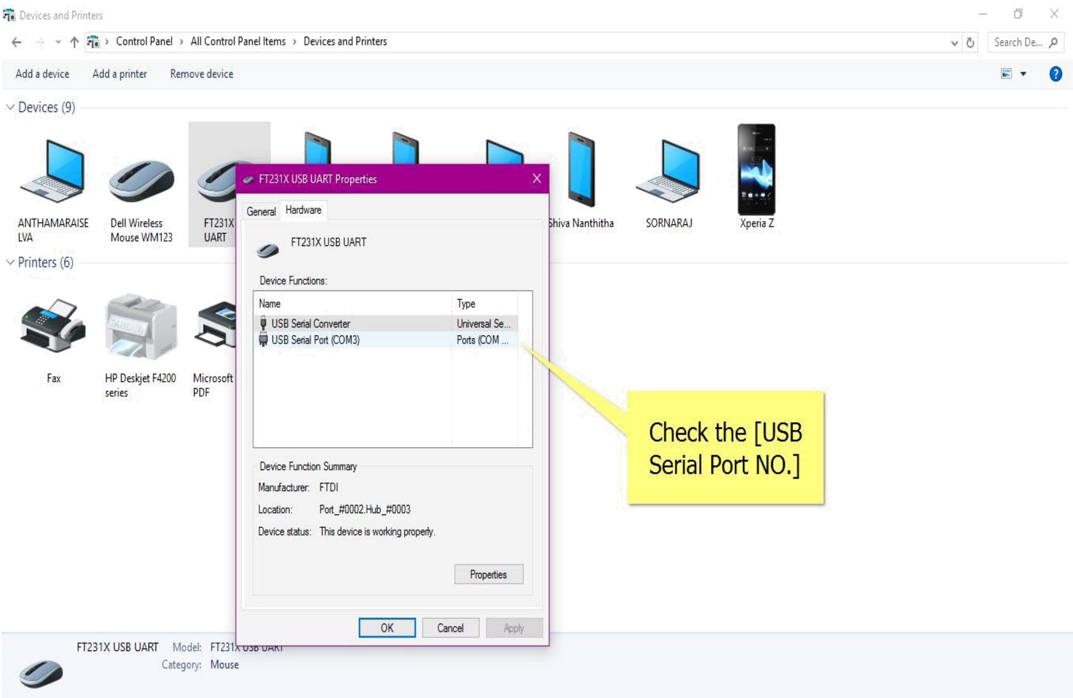


7.5: UAV-Battery Connection

7. Perform Steer Test to check the Control Surfaces (Elevons) for Pitch and Roll.

8. Connect the Telemetry to the Ground Station using the following steps: Go to Start → My Computer → Devices and Printers → Check the COM Port Number of the Telemetry.

7.6: Telemetry Connection



7.6a: Checking the COM port number

7.4 Flight Planning

7.4a Setting up Mission Planner

Mission Planner is the open-source software interface commonly used to fly drones. The version depicted in this manual is 1.3.52 build 1.3.52.0. Follow the steps mentioned below to set up the Mission Planner.

1. From the top right corner drop down menu, select the COM port number of the telemetry.
2. Set the baud rate as 57600 for wireless communication, and 115200 for wired communication.
3. Click the Connect icon shown at the top right corner.
4. Wait for the Mission Planner to fetch the data and start initializing.
5. While initialization, cover the holes on the Pitot tube (air speed sensor) with your fingers.
6. After successful connection, your plane should respond to the joystick movements.
7. Check the flight data and sensor inputs correspondingly then wait for GPS status to change to GPS: GPS 3D FIX.

Screenshot for Step 1

Screenshot for Step 2

Screenshot for Step 3

Screenshots for Step 4

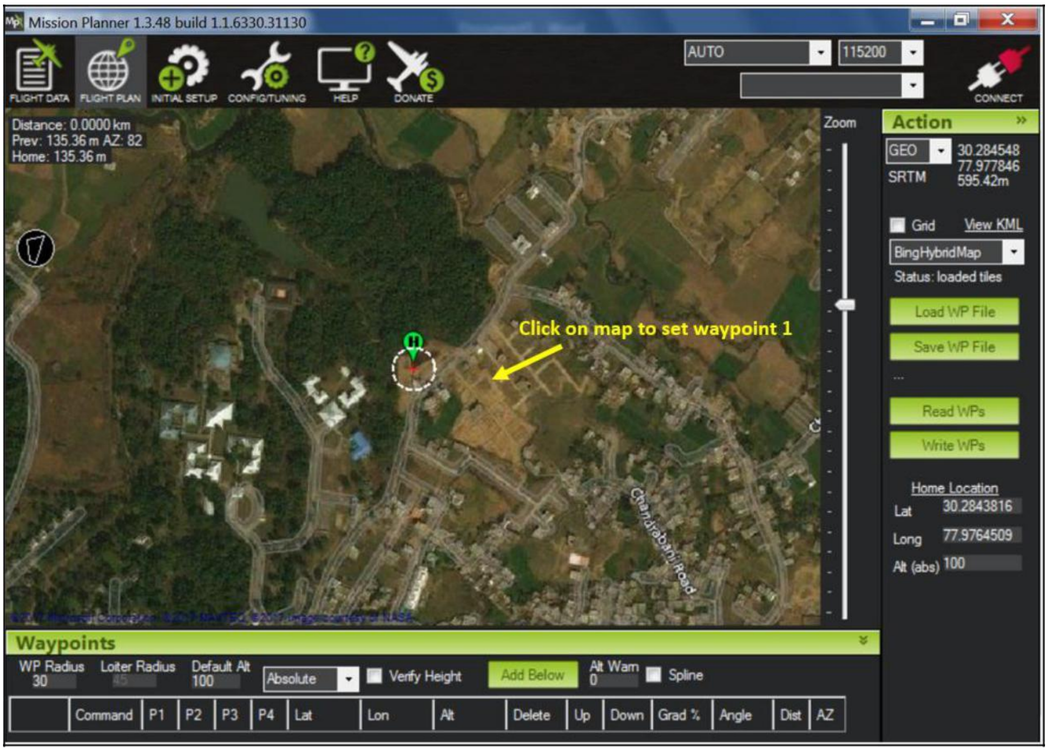
Screenshot for Step 7

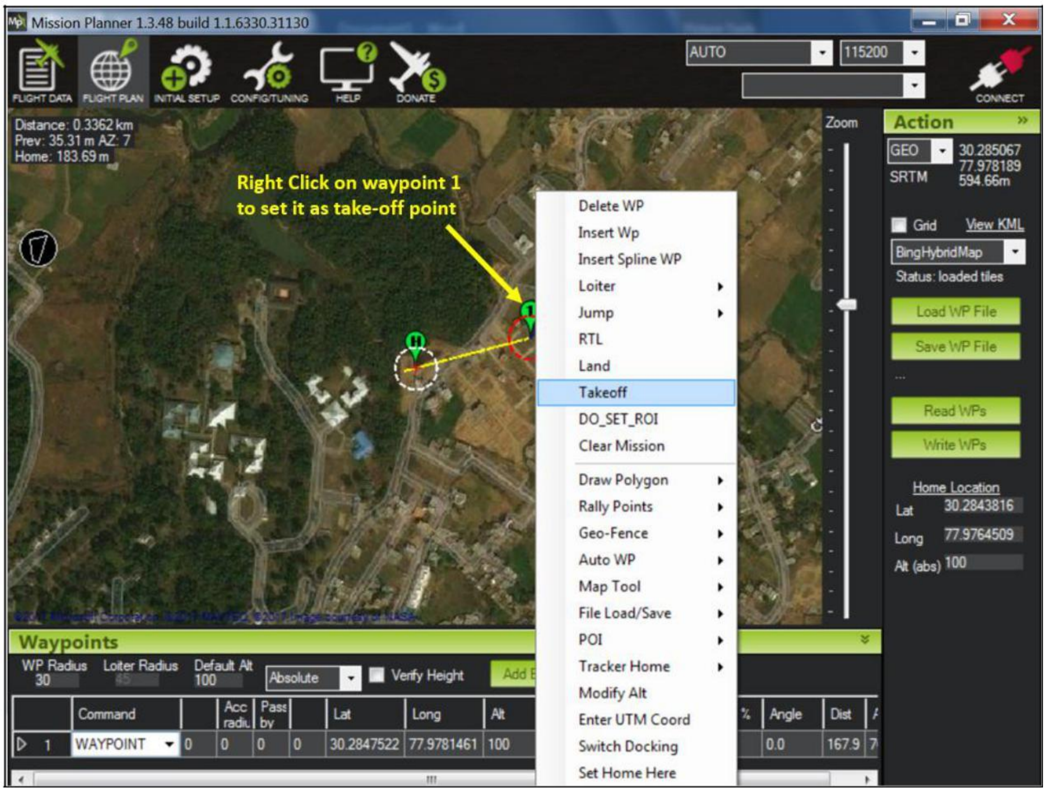
7.4b Creating an Offline Mission

1. Set the HOME position near the launch area.
2. Assess the area.
3. Click on the map and set waypoint 1 as the take-off point.
4. Set the relative altitude of waypoint 2 to minimum 40 meters to avoid collision with tall trees. If the area has mountains, then the altitude of waypoints should be more than their height for safe flight.
5. The distance between waypoint 1 and waypoint 2 must be at least 40 meters.
6. Add consecutive waypoints as per your desired choice (keep minimum distance between waypoints as 20 meters).
7. The last waypoint is the landing point; this must be set to RTL/RTH (Return to Launch/Return to Home).
8. In case, RTL is not desirable/executable, choose the landing point near the HOME position.
9. The distance between the final waypoint and the landing point should be at most 40 meters. The total distance of the mission is displayed in the top left corner.
10. Save the mission.

Screenshot for Step 1

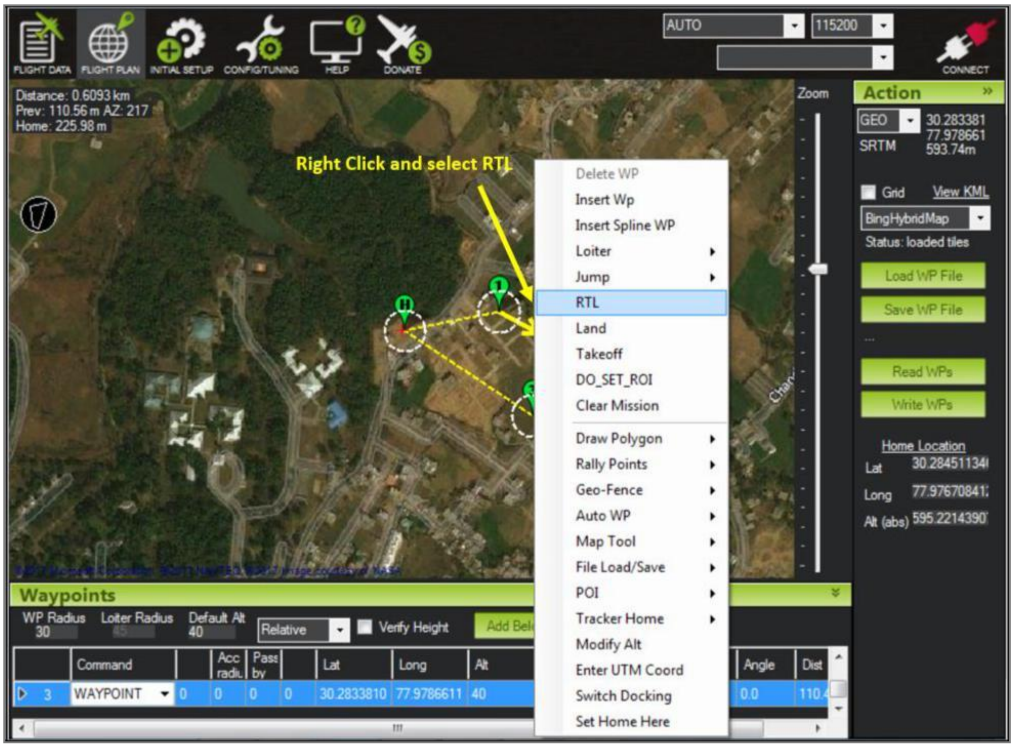
Screenshot for Step 3





Screenshot for Step 5

Screenshot for Step 7 (part 1)



Screenshot for Step 7 (part 2)

Screenshot for Step 7 (part 3) and Step 8

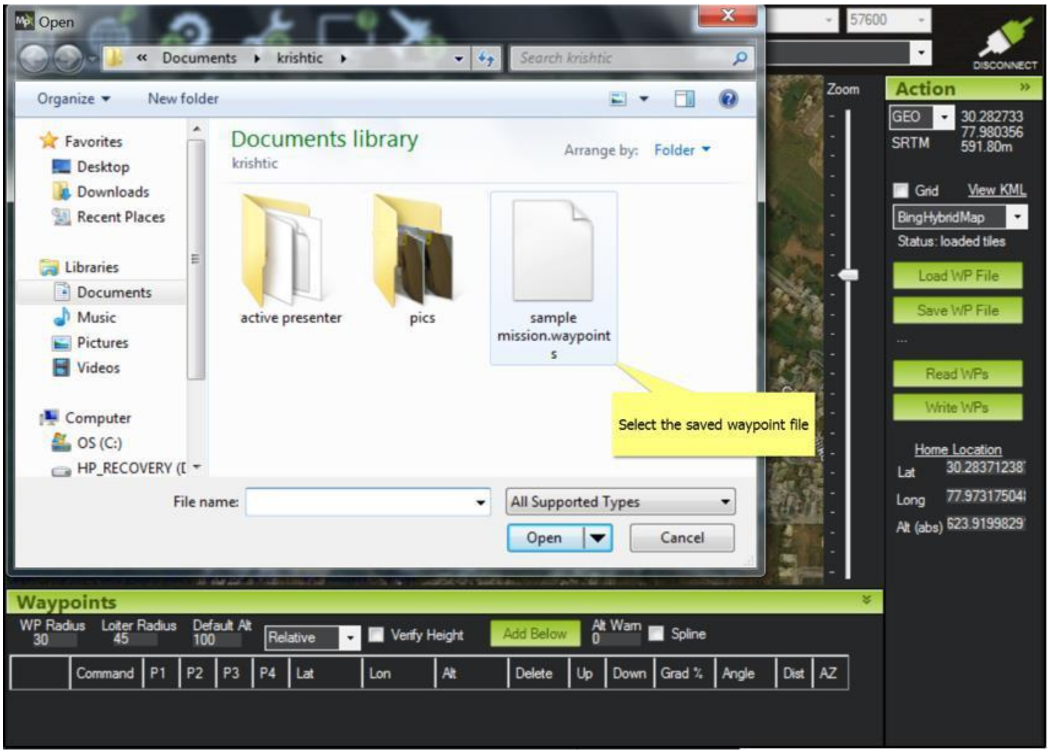
7.4c Uploading the Mission

1. Click on 'Load WP' (waypoint) file.
2. Choose the saved mission (waypoint file) from its folder location and click on Open.
3. The planned mission will be displayed on the map.
4. Click on 'Write WPs'.
5. Click on 'Read WPs' to confirm that the mission is uploaded to the drone.
6. Click on 'Flight Data' button on the top left corner.
7. The given mission is now uploaded.
8. Switch to Auto Mode using the remote controller.
9. The drone is ready for launch.

Note: The co-pilot must be alert throughout the mission.

Screenshot for Step 1

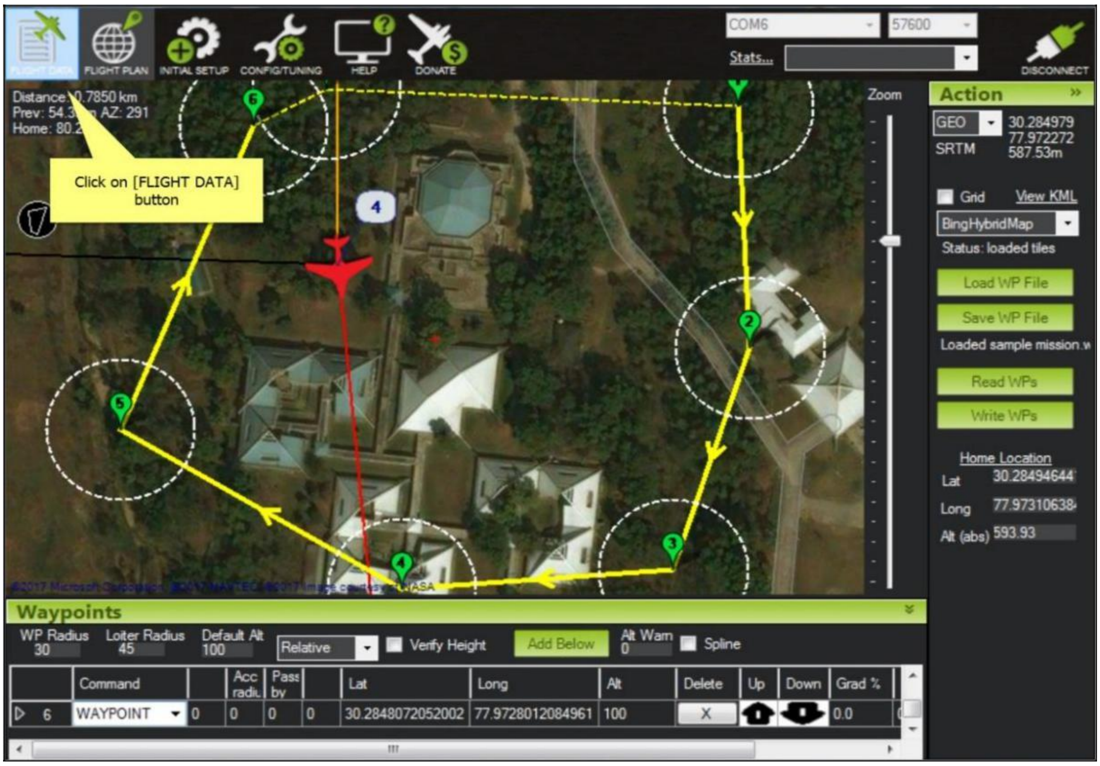
Screenshot for Step 2



Screenshot for Step 4

Screenshot for Step 5

Screenshot for Step 6



7.5 In-Flight Monitoring

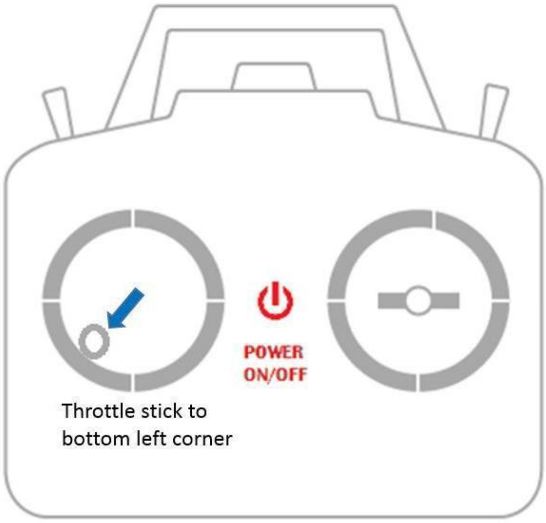
Screenshot showing parameters for In-Flight Monitoring

The aircraft's flight path and its heading direction should be monitored regularly. Battery percentage, altitude, telemetry health and GPS strength are the most important parameters in flight and should be checked continuously. In emergency situations, RTL/RTH function must be used to bring the aircraft back to home safely.

RTL/RTH function should be used if:

- The battery percentage is low below safe level in flight.
- The strength of telemetry signal is getting weaker below safe level.
- The plane is not following the original flight path.
- The weather condition becomes unsafe to fly for example wind speed increases or raining starts.

7.6 Post-Flight Checks



7.7: Disarming the Drone

1. Disarm the Drone by moving the throttle stick to the bottom left corner on the Radio Control (as shown in figure 7.7).

2. Disconnect the battery of Drone.
3. Switch OFF the Transmitter/Radio Control.
4. Power OFF the camera.
5. Power OFF any additional equipment.
6. Inspect Drone for physical damage (check for loss of components, if any).
7. Repair the damaged structure and replace the missing parts, if any.
8. Clean the motor and servos using a blower.
9. Copy the Image/Video data of the camera from the memory card to the computer as well as maintain a back-up of the data in an external hard disk drive.
10. Format the memory card and replace it inside the camera.
11. Repeat the same process for other missions.
12. After the missions are completed, carefully place the drone inside the case to keep them safe.
13. Save the mission log file on disk and have a back-up copy of the same.

8

Capacity Building (Flying Skill Development)

This section deals in training methodology and preparation of the staff for flight operation and manual flying. Flying a UAV requires prior training which is mandatory and cannot be avoided as these aircrafts function in a way similar to that of a full sized manned aircraft.

It is recommended that the operator should not directly venture into flying the UAV without proper training and understanding of the flight dynamics. Safety standards of high level must be maintained at all times.

The training phase is divided into three parts to familiarize the operator with the basics of flight and to improve upon his/her flight skills in a systematic way.

8.1 Basic Training

This phase includes with the familiarization of the operator with the basics of flight using theoretical classes and videos. This phase is further divided into:

1. Flight Principles.
2. Manual control operations, Take Off/Landing.
3. Flight planning and connection setup.

8.2 Intermediate Training

This training includes using Flight Simulator software to train the operator in virtual environment. Here the operator is trained to fly a trainer aircraft which is easy to fly because of its light airframe and high stability. Trainer aircraft is used for fixed winged training and a quadcopter for multirotor training in a simulated environment. At least 20 hours of flight training is required on simulator to move on to the advance level. This phase is further divide into:

1. Simulated Take Off/ Landing for fixed wing.
2. Simulated flying and handling of fixed wing and multirotor.
3. VTOL operations.

8.3 Advanced Training

This is the final phase where the operator is trained to fly in real environment in the supervision of a flight trainer. Here the operator is allowed to take a solo flight using a model trainer aircraft.

A minimum of 30 hours of flight time is required to complete the advanced training phase.

During this phase, the operator’s capability to take-off and land, in-flight maneuverability and the fluency of all these parameters is assessed. If there is a moderate increase in wind speed during the flight, the operator must be able to handle the aircraft without much difficulty.

After successful completion of advanced training, the operator can now fly independently without any supervision. The operator is also capable to train other beginners, if required.

9

Examples of Drone-based Wildlife Management

With the advent of this new technology, the traditional methods used for wildlife conservation and research can now be improved upon. Incidents such as poaching and illegal logging within protected areas are increasing exponentially, which has degraded the quality of habitat, inevitably affecting the quality of biodiversity in a given area. Drone can be used as a technological tool to combat such issues by patrolling and mapping the area frequently. Furthermore, manual tracking of wild animals is a tedious task involving huge manpower and financial assistance, drones equipped with camera can reduce the time and effort required to perform the monitoring and tracking significantly. In recent years, several organizations have included drones in their arsenal for combating poaching, for example, UAV project in Namibia funded by WWF (World Wildlife Fund for nature) to protect Rhinos has been proven highly effective against poaching. UAVs have become cost-effective and efficient in assisting forest rangers and officials. Shadow-view is another such organization deploying drones in South Africa, Uganda and Ningaloo reef in Australia for monitoring coastline and national parks. Drones cover large areas of coastline or national parks that cannot be accessed on foot. They are also effective in monitoring movements of animals and for documenting evidence regarding illegal activities.

Organization	Model of UAVs in Use	Application
Nicholas School of the Environment, USA	Sensefly-eBee	Mapping across different marine and conservation projects Counting of seals using Thermo-map
Conservation Drones, USA	Hobby-king Bixler, Datamule	Orangutan nest counting in Borneo
Shadow View, WWF	Custom made Fixed-wing aircraft	Rhino, Elephant conservation and monitoring in Namibia
National Oceanic and Atmospheric Administration, NOAA	Custom made hexacopter	Studying killer whales and collecting whale snots, Vancouver, Canada
University of Adelaide, Monash University	3D Robotics X8 Octocopter, FX79 Fixed-wing airframe	Counting and estimating bird population using drones, Macquarie Island, Australia

9.1: Applications of Drones in Various Fields
*this list is not exhaustive

Wildlife Conservation	Plant Conservation	Forestry	Terrain Modelling
Animal/flock counting	Plant health/stress analysis	Vegetation health analysis	Morphology
Camera trap image retrieval	Biomass estimation	Forest mapping	Riverbanks
Animal tracking	Growth coverage monitoring	Storm damage assessment	Cliff faces
Nest surveys	Plant/tree counting	Deforestation / illegal logging incursion monitoring	Coastal area mapping
Anti-poaching activities	Species identification	Fire detection and tracking	3D terrain modelling

9.2: Ongoing Applications of UAVs in Wildlife Conservation

Project E-Bird

This project titled 'E-Bird Technology for Tiger Conservation: Development and Integration of Unmanned Aerial Vehicles as Surveillance and Monitoring Tool for Protection of Tigers and Capacity Building of the Frontline Staff' is a new initiative in the large-scale application of UAVs in the field of wildlife conservation. The project has been conceived collaboratively by Wildlife Institute of India and National Tiger Conservation Authority to develop technological option for effective conservation efforts. It aims to initially demonstrate and over time build capacity of the frontline staff to adopt UAVs and additional modern tools on a regular basis so that specific problems could be handled with the assistance of technological involvement.

Objectives of Project E-Bird

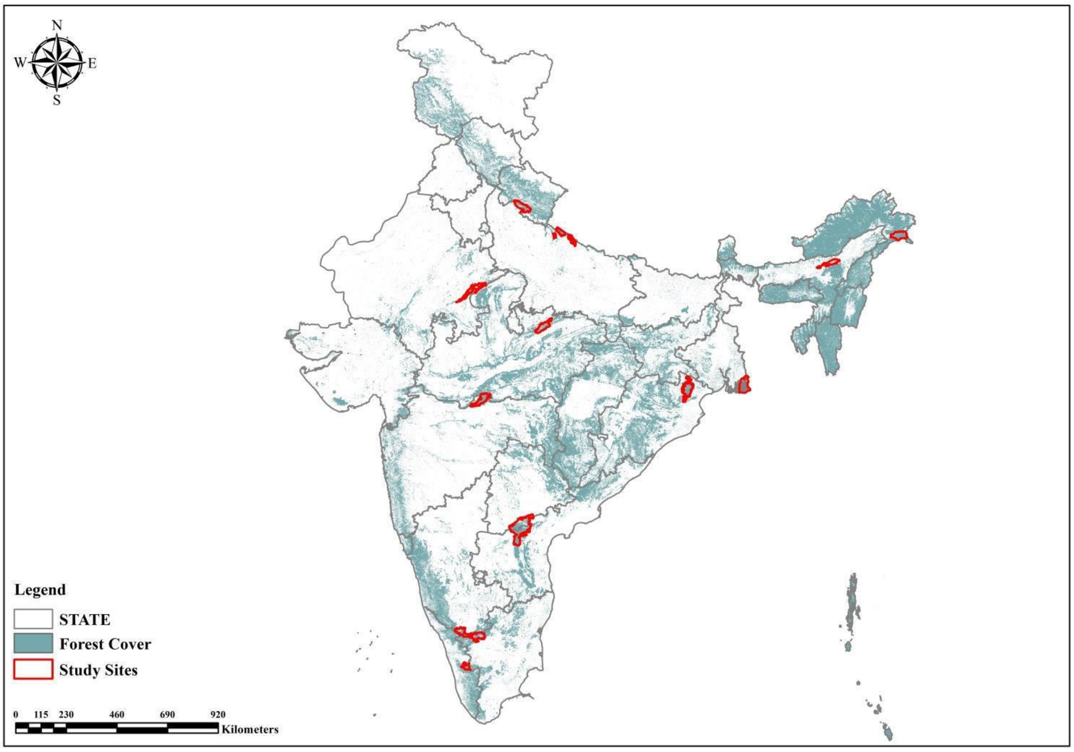
1. To undertake need and feasibility analysis for integration of UAV in representative Tiger Reserves of the country with reference to poaching risk and conflict management strategies.
2. To map locations of poaching and conflict prone areas in the tiger reserves, which would serve as a basis for technology integration.
3. To experiment and implement UAV technology in phased manner in the representative Tiger Reserves for day-time aerial surveillance in strategic locations, night patrolling, mapping and monitoring of

encroachment or degradation, data collection from camera traps and tiger monitoring involving RFID technology.

4. To undertake capacity building of field staff for technology transfer and implementation of UAV technology as a part of regular management strategy.

Project Sites

The project would essentially target all the Tiger Reserves of the country, but initial efforts would be made in representative reserves in all tiger landscapes in different phases of time scale over the five-year period. The specific needs in each of the sites would be determined based on need and feasibility analysis subject to clearances from the concerned agencies such as Director General of Civil Aviation (DGCA) and Ministry of Defence (MoD). Phase I (2015-2017) would be utilized for pilot implementation, need and feasibility analyses, identification of vulnerable sites from the perspective of conflict and poaching risks and implementation of UAVs in Corbett, Dudhwa, Panna, Sathyamangalam and Sundarbans Tiger Reserves. In the Phase II (2017-2019), the implementation will be carried out in other selected sites systematically along with capacity building of field staff and technology transfer.



9.3: Map showing selected study sites for Project E-bird

No.	Landscape Complex	Names of Tiger Reserves	States
1	Shivalik Hills and Gangetic Plain	Corbett	Uttarakhand
2		Dudhwa	Uttar Pradesh
3	Central India and Eastern Ghats	Ranthambore	Rajasthan
4		Panna	Madhya Pradesh
5		Melghat	Maharashtra
6		Similipal	Odisha
7		Nagarjunasagar-Srisailam	Andhra Pradesh & Telangana
8	Western Ghats	Bandipur	Karnataka
9		Sathyamangalam	Tamil Nadu
10		Parambikulam	Kerala
11	North East Hills and Brahmaputra Flood Plains	Kaziranga	Assam
12		Namdapha	Arunachal Pradesh
13	Sundarbans	Sundarbans	West Bengal

9.4: List of Tiger Reserves in different tiger landscapes
where UAV implementation is proposed during the project period

Drones currently being used at WII		Model Name	Remotes being used	Other Compatible Remotes	Flight-Planning Software		
					Windows	Linux	Macintosh
Multi-rotor	Quadcopter	Tarot 650	Fly-Sky	Turnigy, Futaba	Mission Planner 1.3.52.0	APM Planner 2.0	APM Planner 2.0
Fixed-wing	Plane	Volantex FPV Raptor V2					
	Delta-wing	Sonicmodell AR	Multiplex Smart SX	Turnigy, Futaba, & Fly-sky			
		Caipy-1					
		Caipy-2					
		Caipy-3					
		Caipy-4					
		Vanguard					

9.5: Drones and Remotes currently in use for Project E-bird

Appendix A

Propulsion Systems for Drones

Drones require certain kind of propulsive power to function according to their application, each power plant has their merits and de-merits.

These are classified as follows:

A1: Electric Motor

1. **Electric Motors**: This type of power plants uses BLDC motors. These types of motors have excellent power-to-weight ratio and high efficiency. They are simple in design with less number of moving parts compared to conventional brushed motors. These design characteristics reduce noise and vibration caused by the motor.

2. **Internal Combustion (IC) Engines**: These are two stroke miniature engines which use liquid fuel such as petrol and nitro-methane mixed with methanol. Their construction is complex as they have multiple moving parts which leads to high vibrations. They produce a lot of noise when compared to BLDC motors.

A2: Internal Combustion Engine

Appendix B

Future Technology for UAVs

1. **Hydrogen Fuel Cells**: This is a second-generation technology for drones which is still under development. With this technology, a drone could fly for multiple hours instead of several minutes' flight time provided by LiPo batteries. There are many limitations in using these fuel cells as the technology is still new and needs a lot of research to make it safe and reliable.

B1: Drone powered by Hyrdrogen Fuel Cell

2. **Hybrid VTOL Drones**: These drones combine the flight characteristics of a multirotor as well as a fixed wing aircraft. They have the ability to take-off and land vertically. Hybrid VTOL drones have longer range when compared to multirotors and can operate from a small area. Further advancement in this technology would utilize the tilt rotor mechanism.

B2: Hybrid VTOL Drone

Hybrid drones are the next generation UAV's which do not need runways for take-off and landing. This technology combined with the hydrogen fuel cell will increase the duration of flight, which would be a breakthrough in the field of scientific research.

Appendix C

Introduction of Artificial Intelligence to Drones

Artificial Intelligence (AI) is the most advanced and innovative technology in the field of computers and robotics. This technology is the future of computing and independent machine learning. It is still in development phase and giving positive results already. The theory is to develop a computer system which is able to perform tasks without the need of human intelligence, such as perception, speech recognition, decision making, and translation between languages.

In this technology, the computer learns and develops while performing the task repeatedly similar to a human brain. It gets better and smarter with time at performing those tasks again and again.

The goal of AI is to implement human intelligence in machines, by creating systems that understand, think, learn, and behave like humans.

Application of Artificial Intelligence in Drones

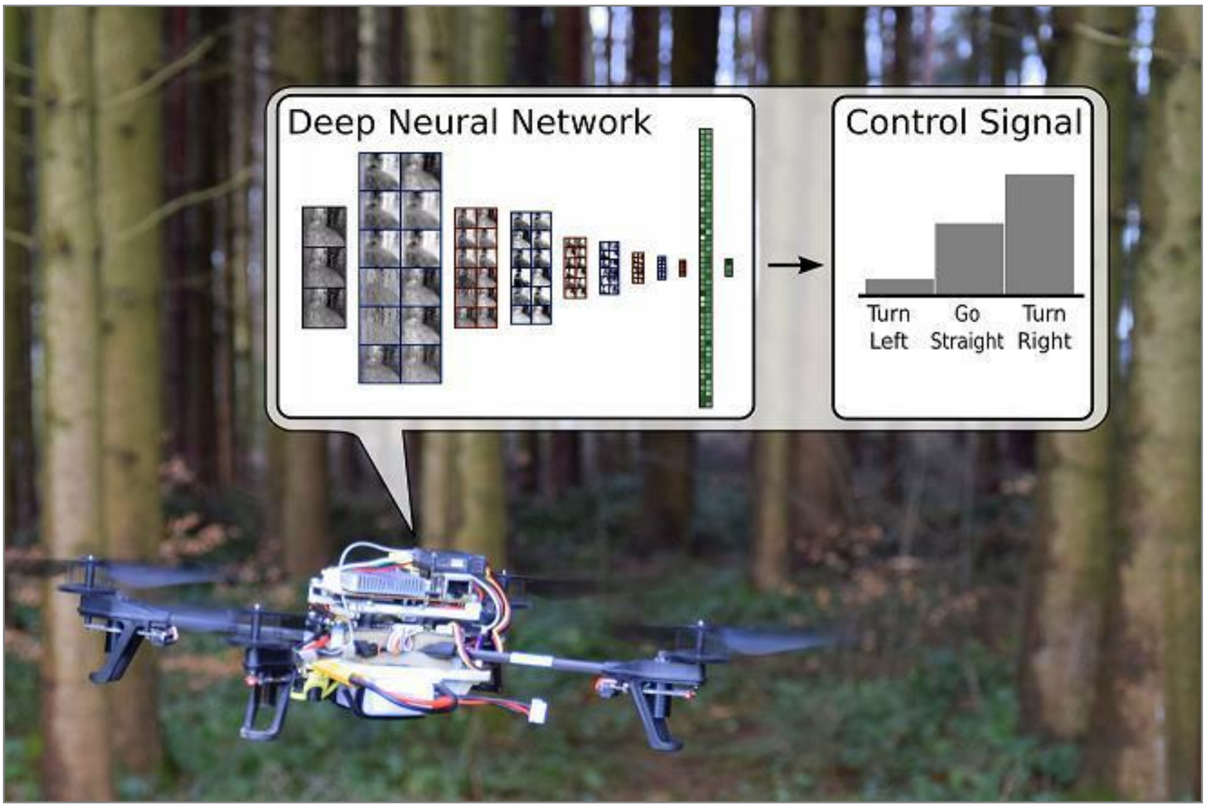
Drones with AI can be used to perform tasks such as monitoring and policing which generally requires human intervention, but after the implementation of AI, human intervention would be limited.

Scientists in Zurich are removing the blinders and letting drones figure things out for themselves. Using "vision algorithms" a group of researchers were able to teach inexpensive off-the-shelf drones to fly autonomously and map surrounding areas.

The algorithms used are a "dense surface reconstruction" data-set designed to teach drones to understand their environment. Using a single camera and an inertial sensor the drones are able to take off, navigate, and create accurate 3D images independently. In the future, drones will be able to fly and navigate on their own while making decisions, recognizing humans, avoiding obstacles and interacting with the environment completely without human aid.

Application of Artificial Intelligence of Drones in Wildlife

Artificial intelligence is the latest and the most advanced phase in drone technology. The fully developed technology can be combined with a flying platform; i.e. an intelligent drone which will access and analyze the situation in real time and process the data without any human assistance. For wildlife it can be used to track, pinpoint and even predict the path of animals, poachers and suspected vehicles.



C1: Neurala's AI

C2: Application of intelligent UAV using GPS and AI

The drone will continuously learn from time to time using different data models and will constantly update its ability to perform wildlife related tasks. The latest example is the Air shepherd program running in Africa for anti-poaching, which is using the AI technology named Neurala's AI which uses The NVIDIA CUDA, Deep Neural Network library (cuDNN) with Tesla P100 GPU's to train their deep learning models.

In Australia a team of researchers are working on an intelligent UAV, which uses its AI technology for automatic identification of animals by comparing data from thermal, day and night vision cameras. The main element of their research is that the data processing has an automatic detection so that you don't have to go through the imagery. The system also has the ability to geo-locate where the wildlife was detected at that point in time. This UAV has a GPS, so each frame captured by the camera is stamped with GPS information.

Researchers can compare aerial counts to 'ground truth' counts conducted manually on foot within the same area to test the accuracy of the system's capability in recognizing patterns from the thermal sensor. During the testing stage, these trials must be administered in areas that are accessible to people on foot, but once algorithms have been fine-tuned and are ready to be applied in the field for wildlife monitoring, they will allow researchers to fly UAVs over areas with dense vegetation that are difficult to access.

Appendix D

Frequency Band Used for Radio Waves

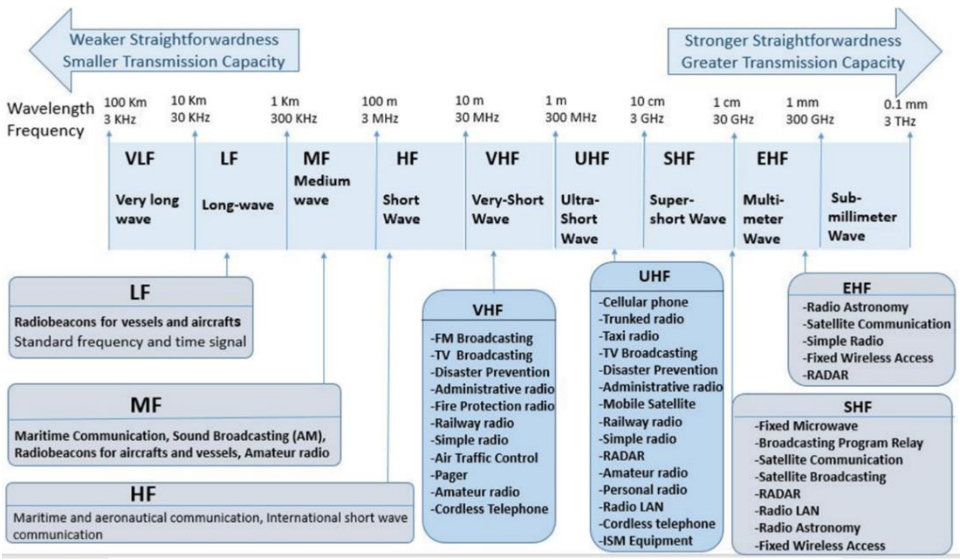
During mission, a UAV requires some mode of wireless communication with the ground station in order to share data as well as for receiving instructions, for this type of communication radio frequency of specific band is used. This radio frequency is an electromagnetic wave which travels in space and works on the fundamental laws of light and waves. Frequency of certain band width is selected according to the required range and data transfer rate.

Name	Wavelength	Frequency (Hz)
Gamma ray	Less than 0.01 nm	more than 10 EHz
X - ray	0.01 - 10 nm	30 EHz - 30 PHz
Ultraviolet	10 nm - 400 nm	30 PHz - 790 THz
Visible	390 nm - 750 nm	790 THz - 405 THz
Infrared	750 nm - 1 mm	405 THz - 300 GHz
Microwave	1 mm - 1 meter	300 GHz - 300 MHz
Radio	1 mm - km	300 GHz - 3 Hz

D1: Frequency Bands

For drone operation we generally use radio waves, because of its simple advantage of penetration through the objects such as walls and trees according to the frequency and also some frequencies have the ability to reflect through the ionosphere so that they can be used for data transfer around the earth. They can carry more information and transfer it at the speed of light, which is also the reason of it being used in cellular and telecommunication industry.

Classification of Radio Frequency



D2: Radio Frequency Classification

1. Very Low Frequency (VLF, 3-30 KHz)

The VLF radio wave has a very long wavelength between 10km and 100km, and it propagates on the ground surface, past small mountains.

2. Low Frequency (LF, 30-300 KHz)

The LF radio wave has a wavelength between 1km and 10km, and it propagates very far. The LF had been in use for radiotelegraphy till around 1930; however, it has not gradually been in use for the purpose as it required a large-scale antenna and transmitting device and the high frequency communication has been largely developed. The LF is partially utilized for the sound broadcasting in Europe, Africa, and some other regions, while in Japan, it is used for Loran C stations for radio navigation, navigation beacons for vessels and aircrafts, and standard frequency and time signal stations providing information on the standard frequency and time signal.

3. Medium Frequency (MF, 300-3000 KHz)

The MF radio wave has a wavelength between 100m and 1000m, and it propagates by reflecting on the E layer of the ionosphere formed at the altitude of about 100km. Because of MF Dario wave's characteristics ensuring stable propagation in a long distance it is suitable for sound broadcasting. While transmission of MF radio wave requires a large-scale transmitter and antenna, only a simple type of receiver is necessary for its reception.

4. High Frequency (HF, 3-30 MHz)

The HF radio wave has a wavelength between 10m and 100m, and it can travel to the opposite side of the planet by repeating reflecting on the F layer of the ionosphere formed at the altitude of about 200-400km the ground surface. As it enables a long-distance communication, it is utilized for ocean vessel communication, aeronautical communication, international broadcasting, and amateur radio communications.

5. Very High Frequency (VHF, 30-300 MHz)

The VHF radio wave has a wavelength between 1m and 10m, and it propagates straightforwardly without getting reflected by ionosphere, this enables it to reach behind mountains or buildings to an extent. It can also carry more information than the high frequency does, it is utilized for the VHF TV broadcasting, FM broadcasting, or mobile communications.

6. Ultra High Frequency (UHF, 300-3000 MHz)

The UHF radio wave has a wavelength between 10cm and 1m, and it has stronger straightforwardness than very short waves does, while it reaches behind small mountains or buildings. It is used for mobile communications as it is suitable for the transmission of a large amount of information with small antennas, transmitters and receivers. It is also used for UHF TV broadcasting.

7. Super High Frequency (SHF, 3-30 GHz)

The SHF radio wave has a wavelength between 1cm and 10cm. Since it propagates straightforwardly, it is suitable for transmission into a specific direction. As it is suitable for transmission of a fairly large amount of information, it is used for fixed links between telephone exchanges, satellite communications, and satellite broadcasting. Furthermore, it is also used for RADARs.

8. Extremely High Frequency (EHF, 30-300 GHz)

The EHF radio wave has a very short wavelength between 1mm and 10mm. It has a strong straightforwardness similarly to the light, and it is attenuated by rain or mist in a bad weather, resulting in difficulties in propagating in a long distance. Therefore, it is used for short range radio communications such as the simple radio communication for image transmission or fixed wireless access systems. Furthermore, the development of new types of systems such as vehicle collision prevention RADARs, radio LAN, etc. utilizing this frequency band has been in progress.

9. Sub-millimeter Wave/Tremendously High Frequency (THF, 300-3000 GHz)

The sub-millimeter wave has a wavelength between 0.1mm and 1mm, and it has similar characteristics to the light. Currently it is not used for radio communications because its transmission requires large-scale facilities and it is largely absorbed by steam. The sub-millimeter wave is used for scientific studies such as radio astronomy.

Telemetry Frequency for UAVs

Generally, UAVs use 900 MHz, 1.2 GHz, 2.4 GHz and 5.8 GHz frequency bands for FPV and telemetry transmission to ground station. But the legal usage of these frequencies may differ from country to country.

Legal frequency band used in India according to Wireless Planning Commission of India for radio control flying and data telemetry is as follows:

IND08 Following frequencies have been embarked for various purposes in the citizen band:	
Frequency (kHz)	Type of Purpose
26964, 26972, 27036, 27124	Personal Communication Relating to Hobbies
27250, 27260	Radio Controlled Toys/Low Power Electric Gadgets
27004, 27116, 27148, 27156, 27228	Aeromodelling
27140, 27204, 26968, 26976	Mountaineering
27220, 27244	Radio Communication Relating to Sports Events
27012, 27028, 27172, 27212	Communication Requirement in Rural Areas

D3: Legal Frequency Band in India

List of License-free frequencies in India for Wireless usage

1. Frequency Band: 865-867 MHz

IND 39 Low power RFID equipment or any other low power wireless devices or equipment IN THE frequency band 865-867 MHz with a maximum transmitter power of 1 Watt (4 Watts Effective Radiated Power) with 200 KHz carrier bandwidth has been exempted from licensing requirements. (see also GSR 564 (E) dated 30 July 2008).

2. Frequency Band: 2.4-2.4835 GHz

Use: Low power equipment
Power: Maximum transmitter output power of 1 Watt (4 Watts Effective Radiated Power)
Carrier Bandwidth: spectrum spread of 10 MHz or higher
Carrier Bandwidth: 1MHz
IND53 Use of low power equipment in the frequency band 2.4-2.4835 GHz using a maximum transmitter output power of 1 Watt (4 Watts Effective Radiated Power) with spectrum spread of 10 MHz or higher has been exempted from licensing requirement (see also GSR 45E dated 28.1.2005)

3. Frequency Band: 5.150-5.350 GHz, 5.725 - 5875

Use: Low power equipment for Cellular telecom systems including Radio Local Area Networks, Indoor applications
Power: maximum mean Effective Isotropic Radiated Power of 200mW, maximum mean Effective Isotropic Radiated Power density of 10mW/MHz in any 1 MHz bandwidth

4. Frequency Band: 5.825 to 5.875 GHz

Use: Low power equipment
Power: maximum transmitter output power of 1 Watt (4 Watts Effective Radiated Power)
Carrier Bandwidth: spectrum spread of 10 MHz or higher
IND08 Use of wireless equipment intended to be used while in motion or during halts, in the frequency band 26.957-27.283 MHz, with a maximum Effective Radiated Power (ERP) of 5 Watts has been exempted from licensing requirements (see also GSR no 35 E dated 10.01.2007)

5. Frequency Band: 26.957-27.283 MHz

Use: Wireless equipment intended to be used while in motion or during halts Power: maximum Effective Radiated Power (ERP) of 5 Watts Reference: GSR no 35 E dated 10.01.2

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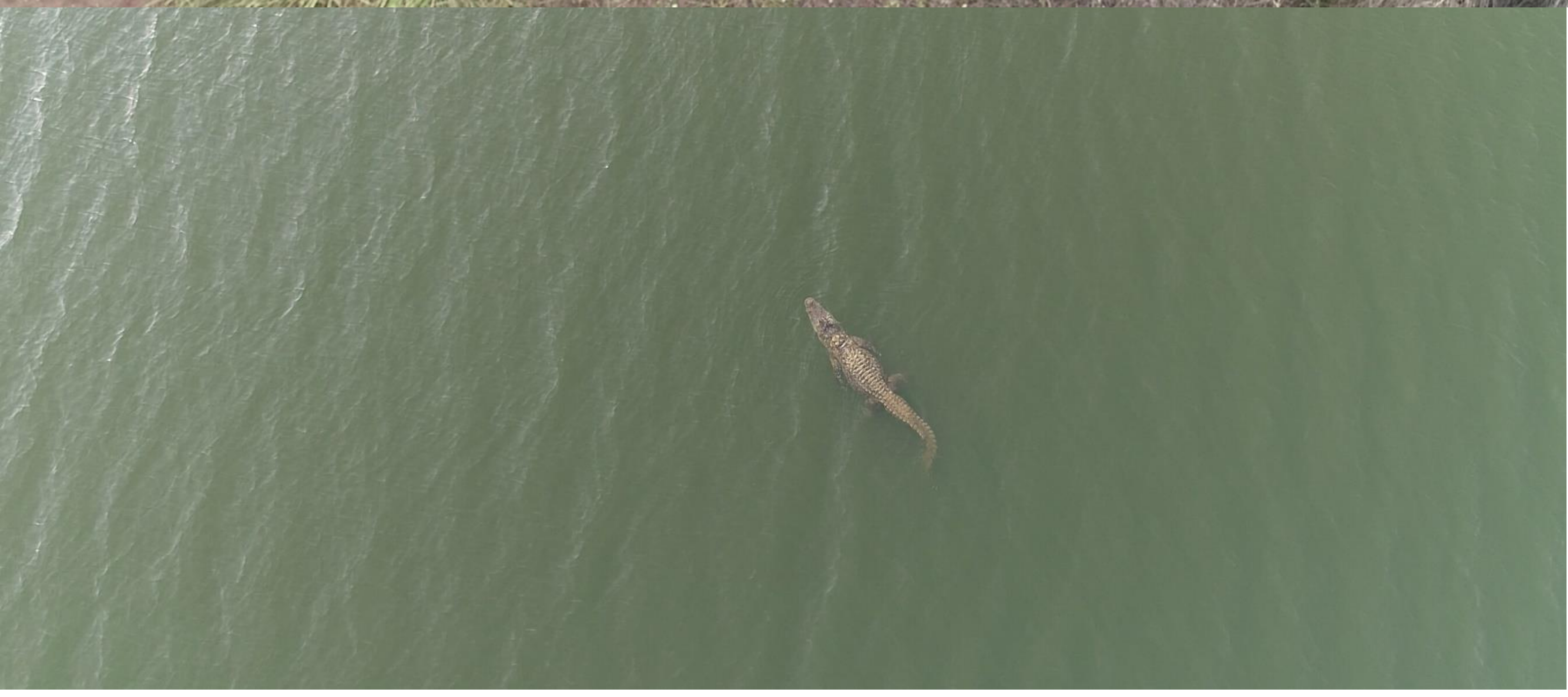

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