Department of Electronics and Communication Engineering

National Institute of Technology, Rourkela

Odisha, India- 769008

Final Year Thesis on

"QUADROTOR"

A detailed Analysis on Construction and Operation

(Under the supervision of

Prof S.K Patra, Dept of ECE)

Submitted by:

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A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

In
Electronics and Instrumantation Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled “**Quadrotor: A detailed Analysis**”, submitted to the National Institute of Technology, Rourkela by **Prannoy Ray, Roll No**. **110EI0252** and **Moti Prakash Panda, Roll No**. **110EI02** for the award of the degree of **Bachelor of Technology** in Department of Electronics and Communication Engineering, is a bonafide record of research work carried out by them under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements. The thesis is based on candidate’s own work, is not submitted elsewhere for the award of degree/diploma.

In my opinion, the thesis is in standard fulfilling all the requirements for the award of the degree of **Bachelor of Technology** in Electronics and Communication Engineering.

Prof. S K Patra

Supervisor

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01.ACKNOWLEDGEMENT

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We would like to thank Mr. Pallav Majhi, our friends and seniors who have helped us to complete the thesis work successfully.

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We thank God for being on our side.

Prannoy Ray

Moti Prakash Panda

02. Abstract

It is a type of an unmanned air vehicle (UAV) which by its name suggests that consists of 4 engines to drive it. Usually we use BLDC motors and propellers as the engines of a quad. Its motion and dynamics can be compared with that of a helicopter in regards to its transverse and longitudinal motion. It has various uses in various fields of military, business, rescue mission, modern warfare etc. They have a vertical take-off and landing system. Unlike a helicopter the propellers or blades of a “Quadrotor” have fixed pitch.

Control of vehicle motion is achieved by altering the pitch and/or rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics. This will be explained in details in course of the following discussion. If we look into history of the “Quadrotor”, we get to know that it was the first step towards vertical take-off and landing vehicle. At first it was a manned vehicle but now mainly the research is focused upon a unmanned “Quadrotor” which is controlled with the help of electronic signals and various other mechanisms.

03. Keywords

- Quad-Rotor
- Aerodynamics
- Propellers Design and Payload
- Arduino Due- Microcontroller
- X-Bee wireless Module
- Stable Flight
- Air Density
- Implementation

04. TABLE OF CONTENTS

06 .PROBLEM STATEMENT:

- To design and manufacture a “Quadrotor” which can be used for aerial surveillance.
- To study the various areas of implementation of “Quadrotor” and its development.
- Mechanical Design Implementation target:
    - It should be cheap and should be light weight
    - It should be able to carry a load i.e. Payload of around 2kgs
    - Maximum time of flight
- Automated Design Implementation target:
    - Should be controlled by laptop/computer so that Quadrotor could receive movement orders from a ground station wirelessly.
    - Fitted with camera(for still images and video), should transfer snapped data to the laptop/computer on ground for “LIVE telemetry data”
    - Should balance on its own in case of turbulence.

6.1 Thesis Contribution

The thesis would focus on the design details of the Quadrotor and then slowly move on to the programming details of the Arduino and XBEE pair and their required configuration. Apart from that, the thesis would also involve optimisation of Flight time by taking into consideration air density, temperature and humidity of the environment and the altitude of the place. Effective design of propellers is also dealt minutely for more efficient power utilisation by minimising speed of motor. Thus the thesis would be better described as an overall view of how a Quadrotor works and its potential in the near future, construction details and areas of research for commercial production and use. The Thesis in total would cover all the possible and potential areas of Quadrotor construction and its engineering beauty.

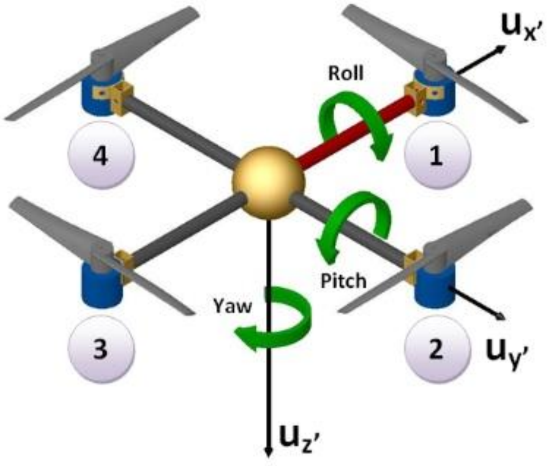
07.INTRODUCTION

7.1 Definition and purpose of a Quadrotor

A **“Quadrotor”,** also called a **quadrotor helicopter**, It is a multicopter that is lifted and propelled by four rotors.

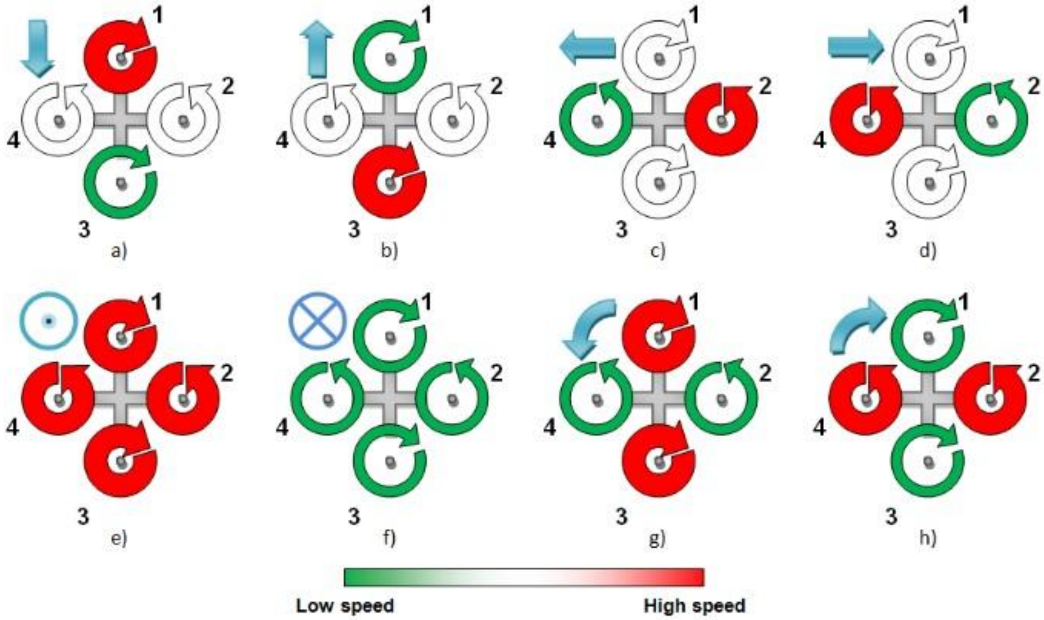
“Quadrotors” are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of revolving narrow-chord airfoils. Unlike most helicopters, “Quadrotors” generally use symmetrically pitched blades; these can be adjusted as a group, a property known as 'collective', but not individually based upon the blade's position in the rotor disc, which is called 'cyclic' Control of vehicle. Motion is achieved by altering the pitch and/or rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics.

7.2 Quadrotor Operation



(More recently “Quadrotor” designs have become popular in unmanned aerial vehicle (UAV) research. These vehicles use an electronic control system and electronic sensors to stabilize the aircraft. With their small size and agile manoeuvrability, these “Quadrotors” can be flown indoors as well as outdoors.)There are several advantages to “Quadrotor”s over comparably-scaled helicopters. First, “Quadrotors” do not require mechanical linkages to vary the rotor blade pitch angle as they spin. This simplifies the design and maintenance of the vehicle. Second, the use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor, allowing them to possess less kinetic energy during flight. This reduces the damage caused should the rotors hit anything. For small-scale UAVs, this makes the vehicles safer for close interaction.

Some small-scale “Quadrotors” have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.



In the last few decades, small scale Unmanned Aerial Vehicles (UAVs) have become more commonly used for many applications. The need for aircraft with greater manoeuvrability and hovering ability has led to current rise in “Quadrotor” research. The four-rotor design allows “Quadrotors” to be relatively simple in design yet highly reliable and manoeuvrable. Cutting-edge research is continuing to increase the viability of “Quadrotors” by making advances in multi-craft communication, environment exploration, and manoeuvrability. If all of these developing qualities can be combined together, “Quadrotors” would be capable of advanced autonomous missions that are currently not possible with any other vehicle.

Advantages of using a quadrotor are as under:

- No gearing is necessary between the motor and the rotor
- No Variable propeller pitch is required for the altering the quadrotor angle of attack
- No rotor shaft tilting is required

- 4 small motors instead of one big rotor resulting in less stored kinetic energy and thus less damage in case of accidents
- Minimal mechanical complexity
- Quadrotors require less maintenance compared to both helicopters and planes
- Rotor Mechanics simplification
- Payload augmentation
- Gyroscopic effects reduction

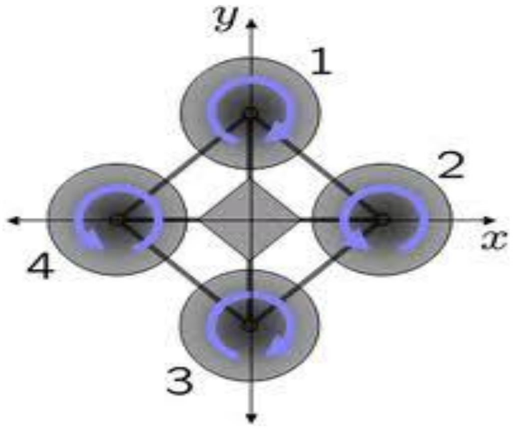
Using GPS for waypoint tracking and altitude, on-board camera and a dual processor capable of autonomous path navigation and data exchange with the ground station. PID controllers each to control pitch, roll, yaw and throttle and their respective gains, can be used to stabilize the system.

Although there are the drawbacks of weight augmentation and high energy consumption, these can be reduced using efficient energy sources and materials engineering research.

08. CONCEPT DESIGN AND DETAILS

8.1 Mechanical Mechanism:-

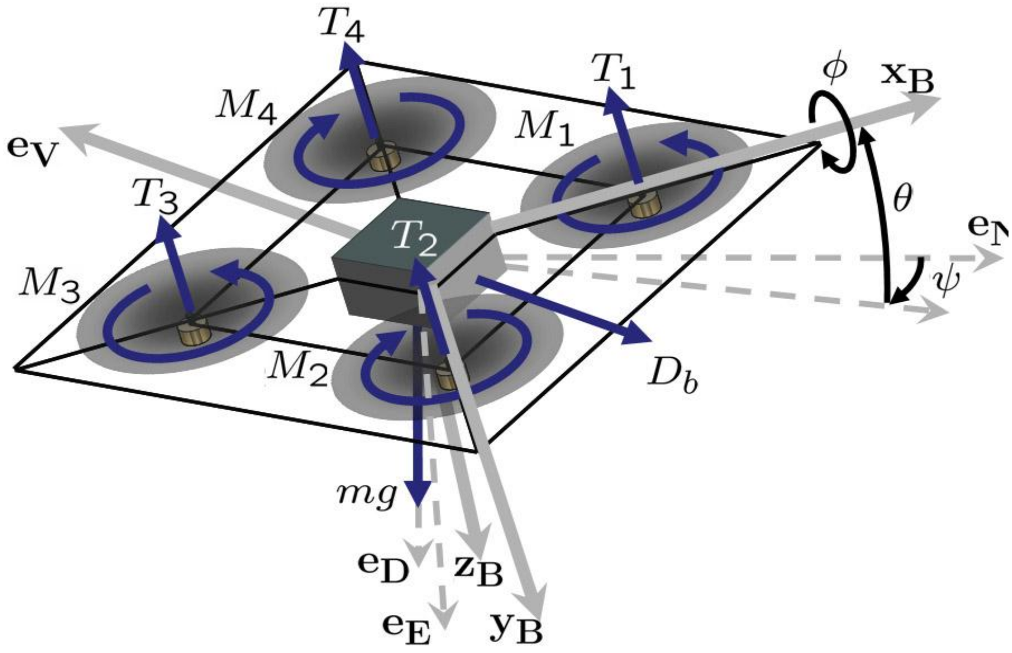
The torque produced in the adjacent motors rotate in different configurations for example if motor 1 and 3 rotate clockwise than motor 2 and 4 will rotate anticlockwise but producing the same thrust and torque due to equal angular velocity. We use **pusher and puller propellers** which have configurations so as to produce an upward thrust rotating in clockwise and anticlockwise directions respectively.



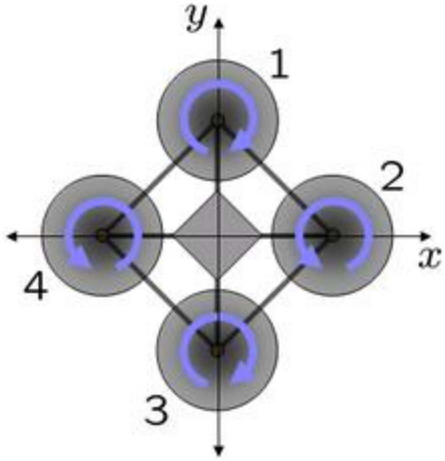
Since a quadrotor has a fixed pitch and so it moves forward by change in the angular velocity of its motors. **Differential thrust** between opposite motors provides **roll** and **pitch torques**. Differential thrust between the two pairs of counter-rotating motors provides **yaw torque**.

The modelling of quadrotor can be done with the help of non linear dynamics.. Let {eN, eE, eD} denote unit vectors along the respective inertial axes, and {xB, yB, zB} denote unit vectors along the respective body axes, as defined in Figure (Free body diagram of a quadrotor). The roll, pitch and yaw angles are controlled by differential thrust. Position control, with respect to the frame is accomplished by controlling the magnitude and direction of the total thrust. A drag force, Db, also acts on the vehicle, opposite the velocity direction, eV.

Below is given the free body diagram which explains the inertial system clearly and different forces on the quad rotor.



8.2 Flight Control:-



Schematic of reaction torques on each motor of a “Quadrotor” aircraft, due to spinning rotors. Rotors 1 and 3 spin in one direction, while rotors 2 and 4 spin in the opposite direction, yielding opposing torques for control.

Each rotor produces both a thrust and torque about its centre of rotation, as well as a drag force opposite to the vehicle's direction of flight. If all rotors are spinning at the same angular velocity, with rotors one and three rotating clockwise and rotors two and four counter-clockwise, the net aerodynamic torque, and hence the angular acceleration about the yaw axis is exactly zero, which implies that the yaw stabilizing rotor of conventional helicopters is not needed. Yaw is induced by mismatching the balance in aerodynamic torques (i.e., by offsetting the cumulative thrust commands between the counter-rotating blade pairs).

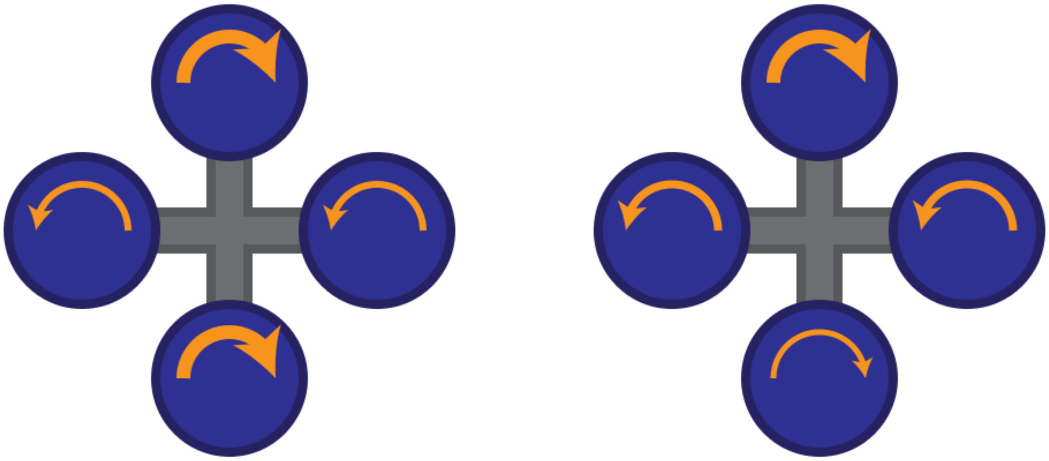
Angular accelerations about the pitch and roll axes can be caused separately without affecting the yaw axis. Each pair of blades rotating in the same direction controls one axis, either roll or pitch, and increasing thrust for one rotor while decreasing thrust for the other will maintain the torque balance needed for yaw stability and induce a net torque about the roll or pitch axes. This way, fixed rotor blades can be made to manoeuvre the quadrotor in all dimensions. Translational acceleration is achieved by maintaining a non-zero pitch or roll angle.

Four rotors are used, rather than three, six or some other number, because four offers two convenient axes of symmetry**. With four rotors it is easy to imbalance side-to-side thrust, thus giving a roll movement.** As this pair of side rotors rotate in the same direction, and one is increased whilst the other is decreased, the overall torque reaction and yawing force remains zero. A similar geometry applies to controlling pitch, using the fore-and-aft rotor pair. The “Quadrotor” design remains inherently in balance for yaw, even as the primary control inputs are changed, thus is easier to learn to fly. In practice, high-end “Quadrotors” today also use on-board gyroscopes to stabilize yaw more precisely.

“Quadrotors” may use either the 'diamond' or 'square' layouts of their rotors. The diamond pattern is slightly easier to understand, as each control axis relies on a single pair of rotors and the others are unaffected. With the addition of a simple **control mixer** though, the square pattern operates just as easily. Like the V Tail of some fixed-wing aircraft, movements of pure pitch or pure roll then rely on a combined input to the two diagonal axes.

Although quadrotor vehicle dynamics are often assumed to be accurately modelled as linear for attitude and altitude control, this assumption is only reasonable at slow velocities. Even at moderate velocities, the impact of the aerodynamic effects resulting from variation in air speed is significant. There are mainly three effects known as total thrust, blade flapping and airflow disruptions. Firstly the total thrust varies not only with the power input but also with the free stream velocity but also the angle of attack with respect to the free stream. The second effect results from differing inflow velocities experienced by the advancing and retreating blades. This leads to “blade flapping” which induces roll and pitch moments on the rotor hub as well as deflection of the thrust vector. The third effect is the interference caused by the vehicle body in slip stream of the rotor. It results in unsteady thrust behaviour rendering attitude control difficult.

The dynamic analysis becomes more complex when we calculate different parameters affecting the motion of a quadrotor. We are here focusing on the fabrication of an automated Quadrotor used for surveillance so we haven’t included other complex analysis and have thus avoided the details.



(The above figures indicate rotational and transitional motion of the quadrotor, respectively based on differential torques exerted by the rotation of motors.)

09. DESIGN DETAILS

The main mechanical components needed for construction are the frame, propellers (either fixed-pitch or variable-pitch), and the electric motors. For best performance and simplest control algorithms, the motors and propellers should be placed equidistant. Recently, carbon fibre composites have become popular due to their light weight and structural stiffness.

The electrical components needed to construct a working “Quadrotor” are similar to those needed for a modern RC helicopter. They are the Electronic Speed Control module, on-board computer or controller board, and battery. Typically, a hobby remote control is also used to allow for human input. “Quadrotors” and other multicopters also often have the ability of autonomous flight. Many modern Flight Controllers use software that allows the user to mark "way-points" on a map and then have their “Quadrotor” fly to those locations and perform tasks such as landing or gaining altitude.

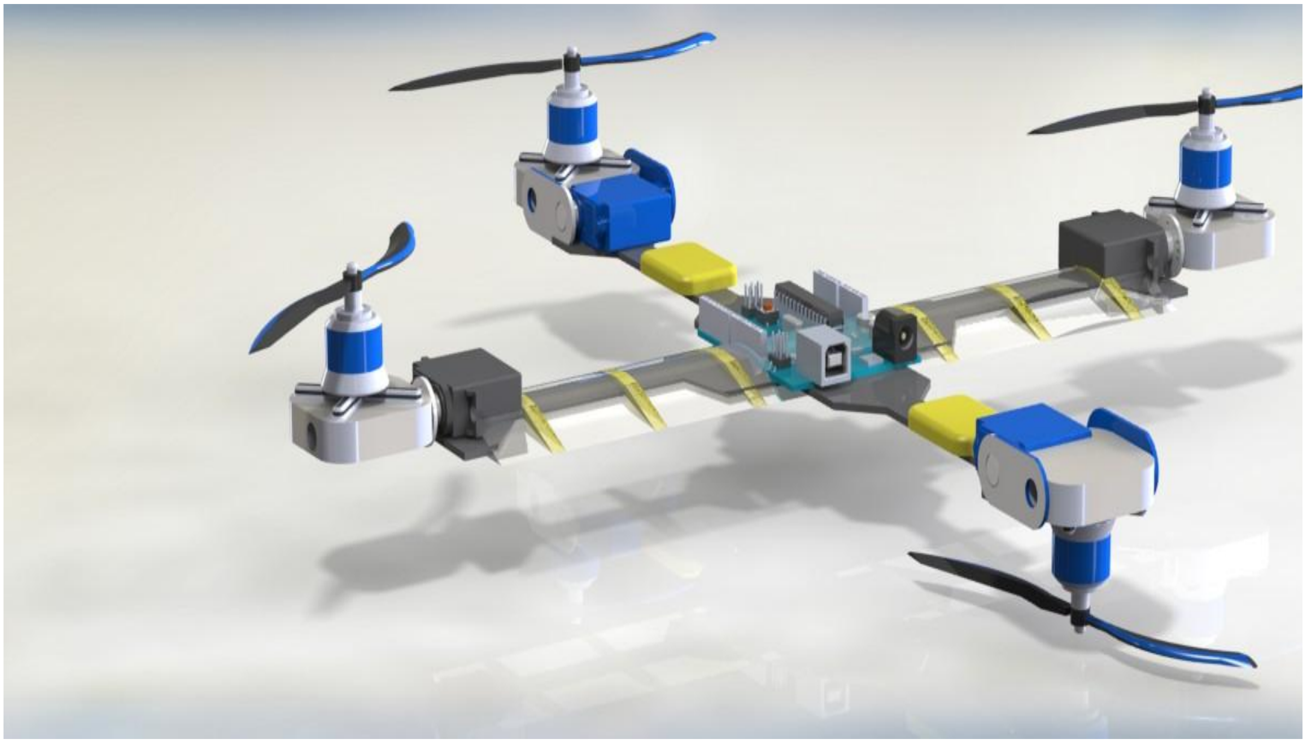
09.1 Design selection:

Concept 1- This design has 4 arms made up of pvc pipes. These are light weight materials and are cheap and easily available.

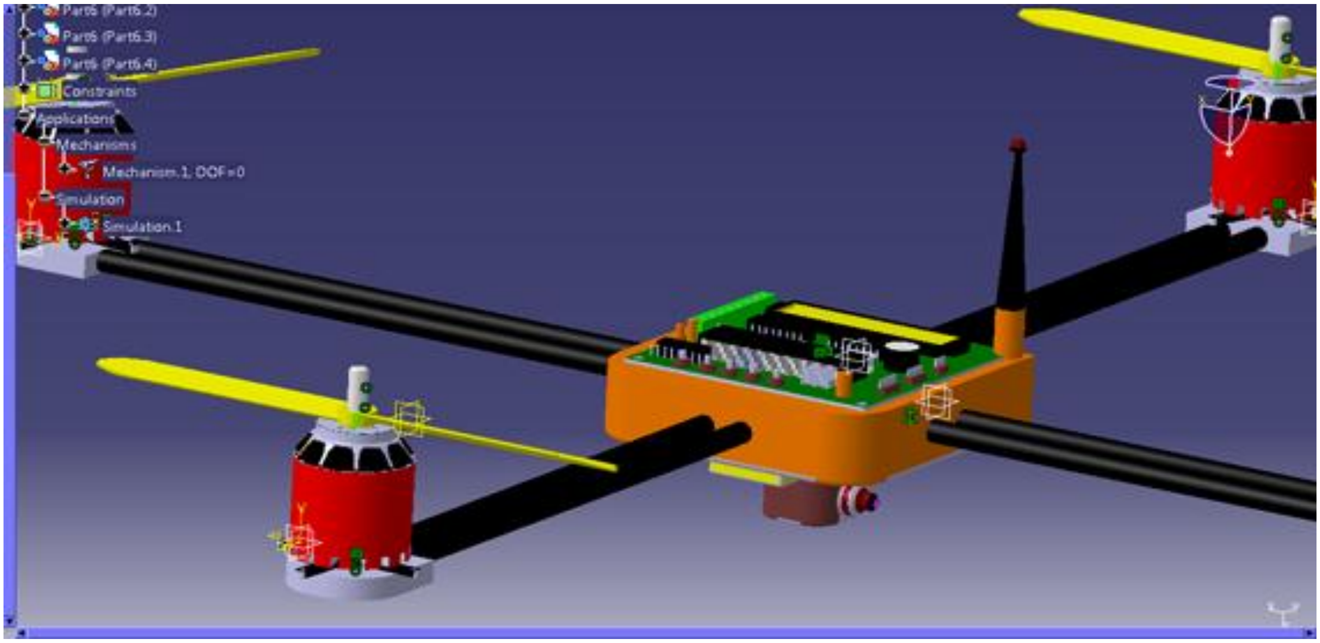
Concept 2- This design has 4 pair of thin arms made up of carbon fibre/polyamide nylon(with brass lining) which is very light and strong to crashes but is costly.

Concept 3- This design has rotating bldc motors for manoeuvring the “Quadrotor”. But its skeleton has flat shaped rods, which leads to air drag.

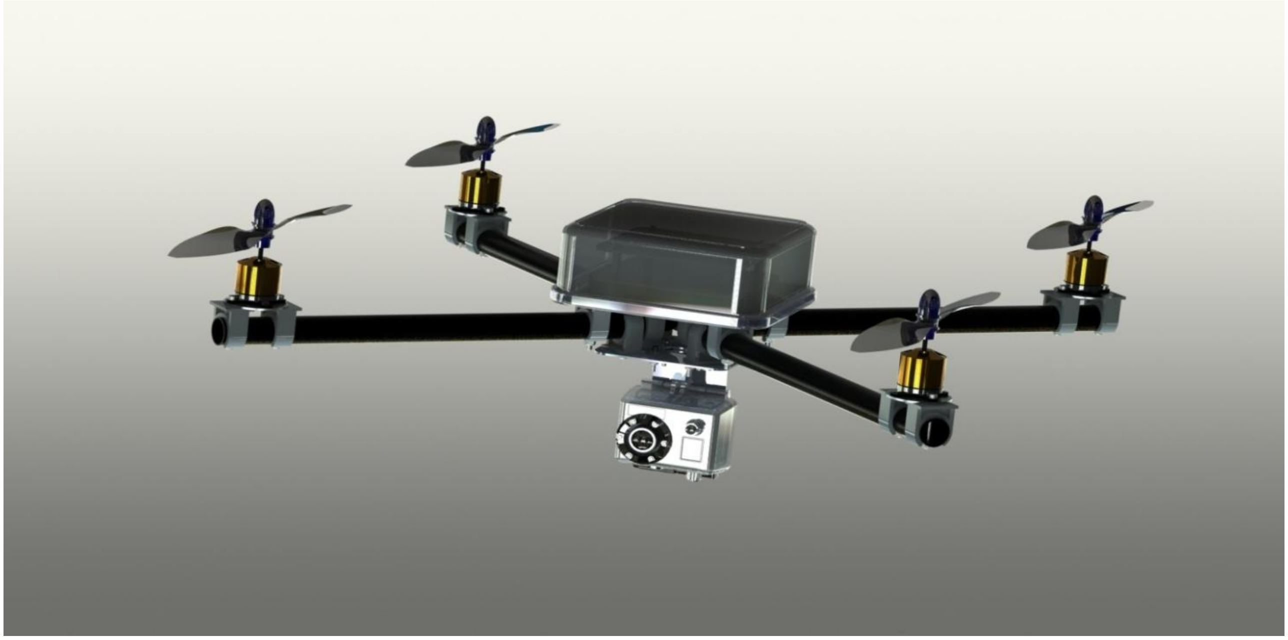
Using SOLID WORKS and CATIA, a three dimensional design of the quadrotor was created to study its behaviour. An effort was put to understand finer details like physical structure and flying mechanism, to finalise on an optimum design for the quadrotor.



CONCEPT 3 (SELF ROTATING MOTORS)



CONCEPT 2 (FIXED MOTOR WITH CARBON FIBRE RODS AS ARM)



CONCEPT 1 (FIXED MOTOR WITH PVC PIPE AS ARM)

We would design our model using Concept-1 or Concept-2.

Concept 2 would be a better option since the construction of the base frame would be hefty and yet not as strong and light as carbon fibre rod.

10. LIST OF COMPONENTS REQUIRED

Parts	**Quantity**	**Approx cost for each component**	**Total (INR)**
Arduino	2 pcs	2000	4000
XBEE pair	2 pcs	4000	8000
Wireless camera module	1 pc	5000	5000
Accelerometer	1 pc	1400	1400
Gyroscope & Magnetometer	1 pc	1500	1500
GPS	1 pc	2500	2500
Ultrasonic range finder	1 pc	1700	1700
RS 232(serial converter)	1 pc	400	400
BLDC motors	5 pcs	3000	15000
ESC (20 amperes)	5 pcs	2000	10000
Battery and Charger	2 pcs	7500	15000
“Quadrotor” frame	1 pc	3000	3000
Pvc pipes	4 pcs	100	400
Propeller pair	2 pcs	500	1000
Other fabrication component	ATR	500	500
Radio controller	1	5000	5000
Total	---		55400

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11. WORKING AND SPECIFICATIONS:

1. N2836, 1500Kv Brushless DC Out runner Motor: - This sturdy size 2836, 1500kv BLDC motor gives maximum thrust of 1200gms and weights only 78gms. It comes with propeller mount with 5mm diameter.

   - (The term **outrunner** refers to a type of brushless motor primarily used in electrically propelled, radio-controlled model aircraft. Outrunners spin much slower than their inrunner counterparts with their more traditional layout (though still considerably faster than ferrite motors) while producing far more torque. This makes an outrunner an excellent choice for directly driving electric aircraft propellers since they eliminate the extra weight, complexity, inefficiency and noise of a gearbox.)

2. 20Amp BLDC ESC: -This is fully programmable 20A BLDC ESC with 5V, 2A BEC. Can drive motors with continuous 20Amp load current. It has sturdy construction with heatsank on the MOSFETs for better heat dissipation. Its weight is 22 gms and size is 47mm x 27mm x 12mm.Max Speed: 2 Pole: 210,000rpm; 6 Pole: 70,000rpm; 12 Pole: 35,000rpm.

   - An **electronic speed control** or **ESC** is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on electrically powered radio controlled models, with the variety most often used for brushless motors essentially providing an electronically-generated three phase electric power low voltage source of energy for the motor.
     - Output: 20A continuous; 25Amps for 10 seconds
     - Input voltage: 2-4 cells Lithium Polymer / Lithium Ion battery or 5-12 cells NiMH / NiCd
     - BEC: 5V, 2Amp for external receiver and servos

3. Propeller :-10inch (25cm) diameter 4.5inch (11cm) pitch matched pair of pusher and puller propellers. Comes with adaptor for 3mm, 3.2mm, 4mm, 5mm, 6mm, 6.35mm, 7.95mm diameter shaft. It is most suitable for Quadrotors.

   - A **propeller** is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade.

4. Frame:- This is a 49.5cm diameter Quadrotor frame with power tracks on PCB for directly connecting ESCs to Battery. Arms are made up of ultra durable polyamide nylon. Arms

have brass inserts with M3 screw threads. Arms can survive repeated crashes without breaking.

5. Arduino – AVR 328 Series of microcontroller which has several features of PWM, Timers, USART, I2C enabling a secure communication to the laptops and other devices. These are reliable, ultra lightweight and low power consumption devices. Atmega series of controllers offer onboard programming facility through which instantaneously programs can be erased and rewritten.
   - **Arduino** is a single-board microcontroller to make using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open-source hardware board designed around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller.
6. X-bee: XBee (S2) 2mw XBee ZB (a.k.a. Series 2) module is used for embedded solutions providing wireless end-point connectivity to devices. This module incorporates the ZigBee PRO Feature with Set mesh networking protocol. Series 2 modules allow you to create complex mesh networks, it does not offer any 802.15.4-only firmware; it is always running

the X-Bee mesh firmware. This module has the lowest current draw of any Digi RF product. However, the infrastructure of a ZigBee network is more complex and requires more configuration to fully implement. This module can give range of 40 meters indoor or 120 meters outdoor

- **XBee** is the brand name from Digi International for a family of form factor compatible radio modules.

7. Accelerometer :The LSM303DLHC is a digital 3 axis accelerometer and 3 axis magnetometer with I2C interface. It has full-scale acceleration range of ±2g to ±16g and full scale magnetic field range of ±1.3 to ±8.1 gauss. All the full scale ranges are user selectable. Module has on board low drop voltage regulator which takes input supply in the range of 3.6V to 6V DC. Board has two mounting holes. All 9 pins of the module are arranged in single line.

   - An **accelerometer** is a device that measures proper acceleration. The proper acceleration measured by an accelerometer is not necessarily the coordinate acceleration (rate of change of velocity). Instead, the accelerometer sees the acceleration associated with the phenomenon of weight experienced by any test mass at rest in the frame of reference of the accelerometer device.

8. Gyro :L3G4200D is a 3 Axis ultra stable digital gyroscope. It gives unprecedented stability of zero rate level and very good sensitivity over temperature and time. L3G4200D module features an on board low drop out voltage regulator which takes input supply in the range of 3.6V to 6V DC. Board has two mounting holes. All 9 pins of the module are arranged in single line.

   - A **gyroscope** is a device for measuring or maintaining orientation, based on the principles of angular momentum. Mechanically, a gyroscope is a spinning wheel or disc in which the axle is free to assume any orientation. Although this orientation does not remain fixed, it changes in response to an external torque much less and in a different direction than it would without the large angular momentum associated with the disc's high rate of spin and moment of inertia. The device's orientation remains nearly fixed, regardless of the mounting platform's motion, because mounting the device in a gimbal minimizes external torque.

9. Ultrasonic Range Finder: EZ1 (EZ Series) is an indoor, compact, low cost easy to use ultrasonic range sensor with narrower beam width than EZ0 Ultrasonic sensor from MaxBotix. It gives range output in terms of analog voltage, serial data and PWM signals. You can cascade many of these sensors together to take distance reading of the

surrounding area without any interference from the adjacent sensor.It detects objects from 15cm to 645 cm (6 inches to 254 inches) with the resolution of 2.5cm (1 inch). It gives range output in the Analog, Pulse Width Modulation (PWM) and in the serial format which makes it very convenient for interfacing.

- **Ultrasonic sensors** (also known as **transceivers** when they both send and receive, but more generally called transducers) work on a principle similar to radar or sonar **which** evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.

10. GPS: -GPS Receiver MT3318 Module from NEX Robotics is based on the SiRF Star III technology. GPS module has on-board compact Ceramic GPS patch antenna. The receiver module can track 20 satellites simultaneously. GPS receiver updates navigation data every second. It gives data output is in standard NMEA information format at the baud rate of 9600bps.

    - The **Global Positioning System** (**GPS**) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

11. Camera: -Wireless Small size spy camera for Surveillance and robotics. The very small size and low power operation makes it useful for mounting on wireless robots to transmit the video to receiver. The received signal can then be directly seen in to tv or in pc through TV Tuner or Video Capture Card. For Laptops USB TV Tuners can be used.
12. Battery: -This is high performance 3 Cell, 11.1V, 5000mAh, 30C Battery. It can give discharge current of 150000Amps. It has ‘T’ type Power connector and 4 pin JS connector.

12. PROGRAMMING AND CONTROLLING

How is wireless communication realised in a quadrotor? Starting from controlling of quadrotor to data transfer, telemetry transfer, plotting graphs etc. To answer that we must go in a sequence to cover all the minute details of the communication.

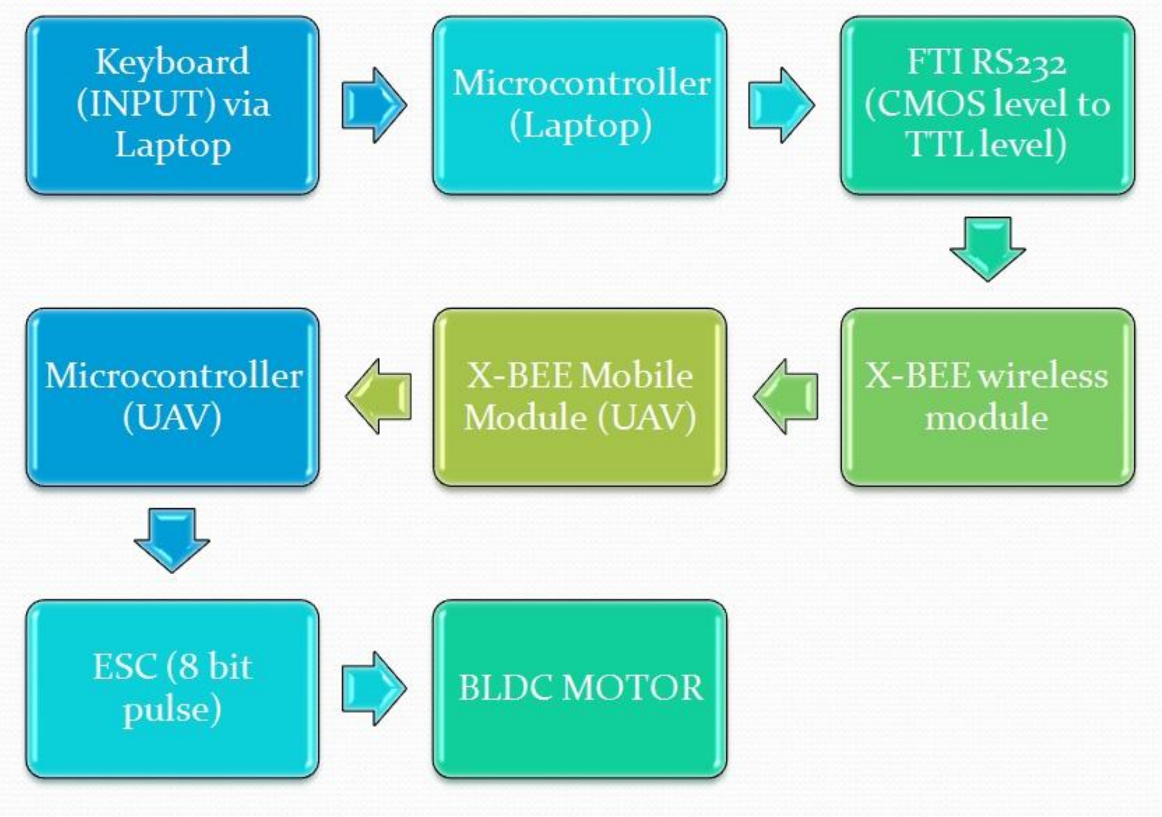
A C++ running in a laptop accessing the open CV library files takes the input from the keyboard as character datatype. Character is converted to binary data type and serial port of the laptop is enabled. 8 bit data is converted to 10 bit data and a start bit is sent to the microcontroller. The micro controller after receiving start bit sends back the feedback bit after which the data is transferred. The various sensor data sent from the microcontroller to the laptop using open CV source can plot data using images sent by the camera using a different protocol.

An FTI RS232 chip is connected to the USB port of microcontroller which converts the CMOS level to TTL level. The serial data is then sent to X-BEE wireless module which is 128 bit encrypted and uses a secure 8 channel connection with the host station.

The data is received by a mobile X-BEE module which decodes the data, converts it to TTL level and sends to the microcontroller. Depending upon the key strokes given, the RPM of BLDC motor is controlled by generating PWM. Timers and interrupters enable an 8 bit pulse which is sent to the ESC controlling the BLDC motor electronically at a constant RPM. The microcontroller has 328 kb of memory on which a pre-programmed path can be saved and the quadrotor can be automated.

GPS device installed gives the global coordinates at 9600 band rate which help in tracking as well as guiding the “Quadrotor” on a planned mission. The “Quadrotor” is gyro stabilized by use of a gyro sensor using I2C interfacing. With this it gives the exact angular acceleration in 3 axes which helps in stabilizing the “Quadrotor” in mid-air. An accelerometer and magnetometer help in finding the direction as well as guiding the quad rotor when GPS is not working. Autopilot feature can also be enabled by use of different codes after the fabrication of the basic model.

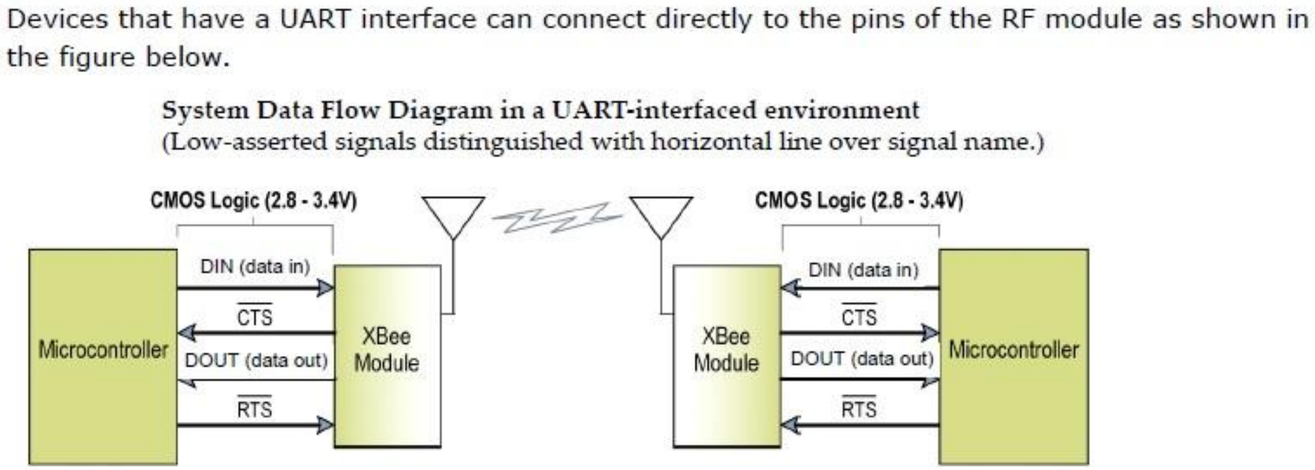
The Above mentioned data is jotted down to the flow diagram below for better reference.



The quadrotor can be controlled via a romote comtroller using RF techniques or via Laptop attached to a XBEE Wireless Module via a Serial Converter.

Now going into details of each of the component, we start with XBEE Wireless Module.

12.1 Our Model used for the project is “XBEE Pro” wireless module. The system data flow diagram is as below:



Devices that have a UART interface can connect directly to the pins of the RF module as shown in the figure below.

System Data Flow Diagram in a UART-interfaced environment
(Low-asserted signals distinguished with horizontal line over signal name.)

The Laptop here acts as the microcontroller (as in the above diagram), thus receiving all the data and can frame the data into a graph when required. In order to connect the XBEE to the laptop we need a USB to Serial Converter i.e RS232. The RS232 formally defines the signals connecting between a DTE(Data Terminal Equipment) and a DCE (data circuit-terminating equipment) such as a modem. Commonly used in computer serial ports, this is used here in order to connect the XBEE module to the Laptop via USB.

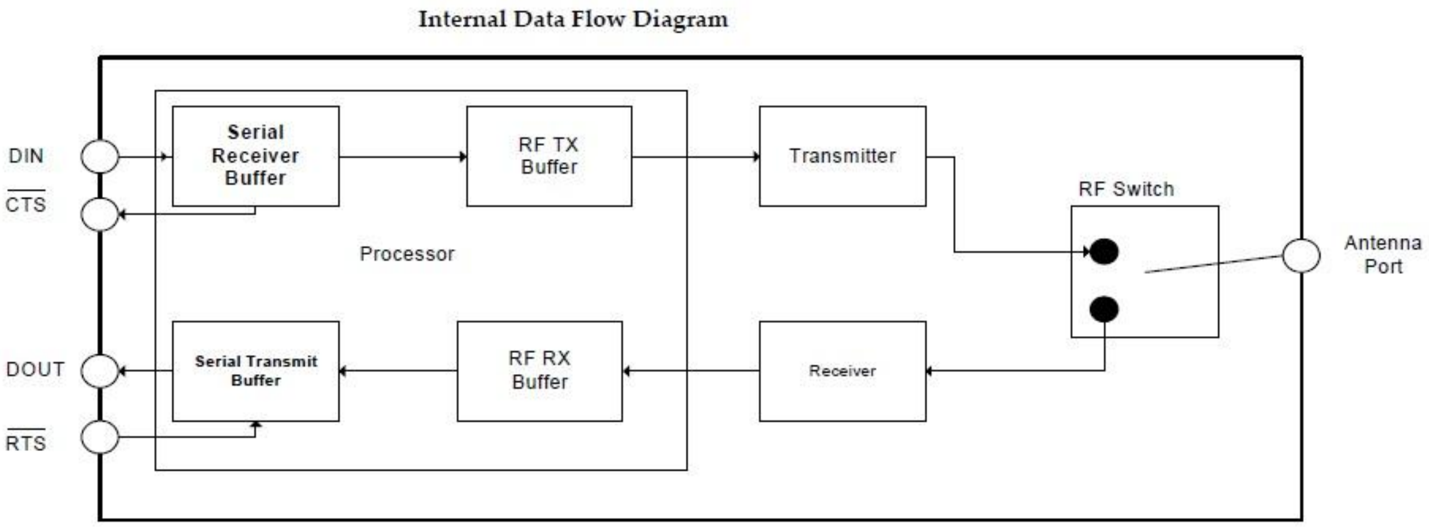
12.1.1 XBEE Design Notes:

- ✓ Minimum connections: VCC, GND, DOUT & DIN
- ✓ Minimum connections to support serial firmware upgrades: VCC, GND, DIN, DOUT, RTS & DTR
- ✓ Signal Direction is specified with respect to the module
- ✓ Module includes a 30k Ohm resistor attached to **RESET**
- ✓ Several of the input pull-ups can be configured using the PR command
- ✓ Unused pins should be left disconnected
- ✓ Pin 20 can be connected to a push button (pin grounded when closed) to support the commissioning push button functionality.

12.1.2 Modes of Operation :

- Idle Mode (When not receiving or transmitting data, the RF module is in Idle Mode)
- Transmit Mode (Serial data in the serial receive buffer is ready to be packetized)
- Receive Mode (Valid RF data is received through the antenna)
- Sleep Mode (End Devices only)
- Command Mode (Command Mode Sequence is issued)

12.1.3 The XBEE internal Design :



12.1.4 Specifications of XBEE pins:

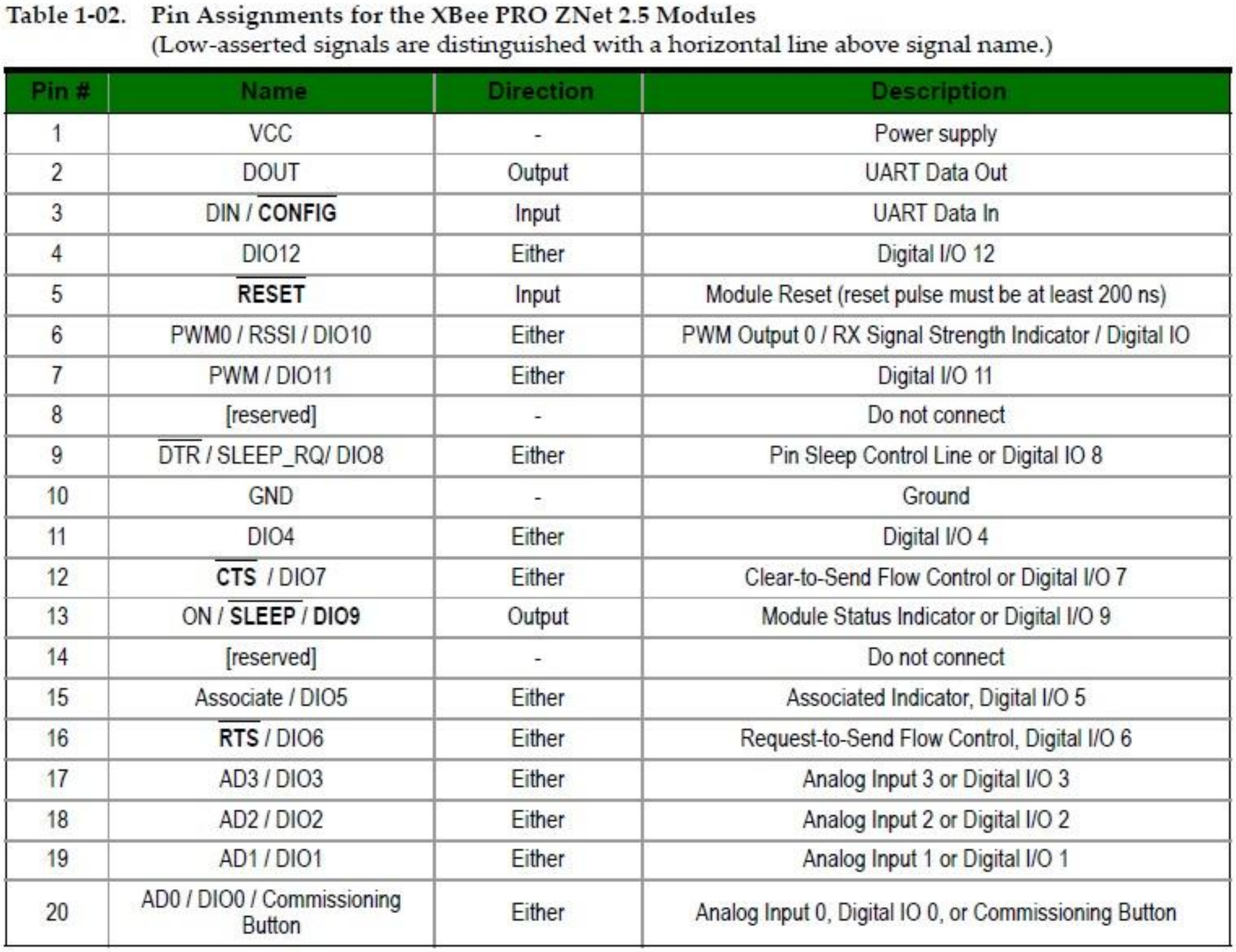
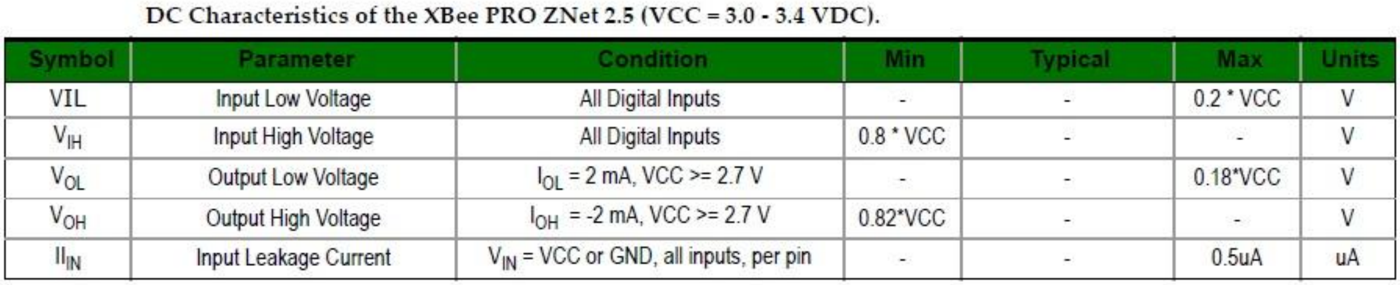


Table 1-02. Pin Assignments for the XBee PRO ZNet 2.5 Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **$\overline{\text{CONFIG}}$**	Input	UART Data In
4	DIO12	Either	Digital I/O 12
5	**$\overline{\text{RESET}}$**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI / DIO10	Either	PWM Output 0 / RX Signal Strength Indicator / Digital IO
7	PWM / DIO11	Either	Digital I/O 11
8	[reserved]	-	Do not connect
9	$\overline{\text{DTR}}$ / SLEEP_RQ/ DIO8	Either	Pin Sleep Control Line or Digital IO 8
10	GND	-	Ground
11	DIO4	Either	Digital I/O 4
12	**$\overline{\text{CTS}}$** / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **$\overline{\text{SLEEP}}$ / DIO9**	Output	Module Status Indicator or Digital I/O 9
14	[reserved]	-	Do not connect
15	Associate / DIO5	Either	Associated Indicator, Digital I/O 5
16	**$\overline{\text{RTS}}$** / DIO6	Either	Request-to-Send Flow Control, Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0 / Commissioning Button	Either	Analog Input 0, Digital IO 0, or Commissioning Button

12.1.5 Electrical Characterstics of XBEE:



DC Characteristics of the XBee PRO ZNet 2.5 (VCC = 3.0 - 3.4 VDC).

Symbol	Parameter	Condition	Min	Typical	Max	Units
VIL	Input Low Voltage	All Digital Inputs	-	-	0.2 * VCC	V
V_{IH}	Input High Voltage	All Digital Inputs	0.8 * VCC	-	-	V
V_{OL}	Output Low Voltage	I_{OL} = 2 mA, VCC >= 2.7 V	-	-	0.18*VCC	V
V_{OH}	Output High Voltage	I_{OH} = -2 mA, VCC >= 2.7 V	0.82*VCC	-	-	V
II_{IN}	Input Leakage Current	V_{IN} = VCC or GND, all inputs, per pin	-	-	0.5uA	uA

Apart from that, in order to use XBEE with any microcontroller, we need to reconfigure the default settings in order to match with the type of micro-controller used. The Reconfiguration programme for XBEE is dumped into it via the RS232 USB to Serial Converter using the “CODE BLOCKS software” which is a open C++ platform for programming.

12.1.6 Programme for configuration of XBEE:

```
#include<iostream>
#include <windows.h>
#include <tchar.h>
#include <stdio.h>
#include<conio.h>
using namespace std ;
void PrintCommState(DCB dcb)
{
    //  Print some of the DCB structure values
    _tprintf(TEXT("\nBaudRate = %d, ByteSize = %d, Parity = %d,
StopBits = %d\n"),
        dcb.BaudRate,
        dcb.ByteSize,
        dcb.Parity,
        dcb.StopBits
        );
}
void SerialPutc(HANDLE *hCom, char txchar)
{
BOOL bWriteRC;
static DWORD iBytesWritten;

bWriteRC = WriteFile(*hCom, &txchar, 1, &iBytesWritten,NULL);
if(!bWriteRC)
{
    printf("error");
}
//cout<<bWriteRC;
return;
}
char SerialGetc(HANDLE *hCom)
{
char rxchar;
BOOL bReadRC;
static DWORD iBytesRead;

bReadRC = ReadFile(*hCom, &rxchar, 1, &iBytesRead, NULL);
if(!bReadRC)
{
    printf("error");
}
return rxchar;
}

int _tmain(
            int argc,
            TCHAR *argv[]
           )
{
   char out;
   DCB dcb;
   HANDLE hCom;
   BOOL fSuccess;
   TCHAR *pcCommPort = TEXT("COM9"); //  Most systems have a
COM1 port
   //  Open a handle to the specified com port.
   hCom = CreateFile( pcCommPort,
                    GENERIC_READ | GENERIC_WRITE,
                    0,    //  must be opened with exclusive-
access
                    NULL, //  default security attributes
                    OPEN_EXISTING, //  must use OPEN_EXISTING
                    FILE_ATTRIBUTE_NORMAL,NULL//  hTemplate must
be NULL for comm devices
                    );
   if (hCom == INVALID_HANDLE_VALUE)
   {
       //  Handle the error.
       printf ("CreateFile failed with error %d.\n",
GetLastError());
       return (1);
   }
    SetupComm(hCom, 2, 128);
   //  Initialize the DCB structure.
//   SecureZeroMemory(&dcb, sizeof(DCB));
   dcb.DCBlength = sizeof(DCB);

   //  Build on the current configuration by first retrieving
all current
   //  settings.
   fSuccess = GetCommState(hCom, &dcb);

   if (!fSuccess)
   {
    cout<<"hello \n";

      //  Handle the error.
      printf ("GetCommState failed with error %d.\n",
GetLastError());
      return (2);
   }
   PrintCommState(dcb);       //  Output to console

   //  Fill in some DCB values and set the com state:
   //  57,600 bps, 8 data bits, no parity, and 1 stop bit.
   dcb.BaudRate = CBR_9600;     //  baud rate
dcb.ByteSize =8;
dcb.Parity = NOPARITY;
dcb.StopBits = ONESTOPBIT;
//dcb.fAbortOnError = TRUE;

/*dcb.fRtsControl = RTS_CONTROL_HANDSHAKE; //
```

```
// set DSRDTR
dcb.fOutxDsrFlow = FALSE; // turn on DSR flow control
dcb.fDtrControl = DTR_CONTROL_ENABLE; //*/
   fSuccess = SetCommState(hCom, &dcb);

   if (!fSuccess)
   {
      //  Handle the error.
      printf ("SetCommState failed with error %d.\n",
GetLastError());
      return (3);
   }
   //  Get the comm config again.
   fSuccess = GetCommState(hCom, &dcb);

   if (!fSuccess)
   {
      //  Handle the error.
      printf ("GetCommState failed with error %d.\n",
GetLastError());
      return (2);
   }

   PrintCommState(dcb);       //  Output to console
/*COMMTIMEOUTS CommTimeouts;
    GetCommTimeouts (hCom, &CommTimeouts);

CommTimeouts.ReadIntervalTimeout = 5000;
CommTimeouts.ReadTotalTimeoutConstant = 5000;
CommTimeouts.ReadTotalTimeoutMultiplier = 1000;
CommTimeouts.WriteTotalTimeoutConstant = 5000;
CommTimeouts.WriteTotalTimeoutMultiplier = 1000;

SetCommTimeouts (hCom, &CommTimeouts);
PrintCommState(dcb);*/
   char txchar;
   int x;
   HANDLE *ptr=&hCom;
   while(1)
   {Sleep(10);
printf("hello \n ");
x=SerialGetc(ptr);
  //  scanf("%c",&out);
       //txchar=getch();
       //txchar=SerialGetc(ptr);
       SerialPutc(ptr,'u');
       //printf("%c",txchar);
       //if(!bWriteRC)
        printf ("%d \n ",x);
        //cout<<iBytesWritten;
   }
   _tprintf (TEXT("Serial port %s successfully
reconfigured.\n"), pcCommPort);
```

```
   return (0);
}
```

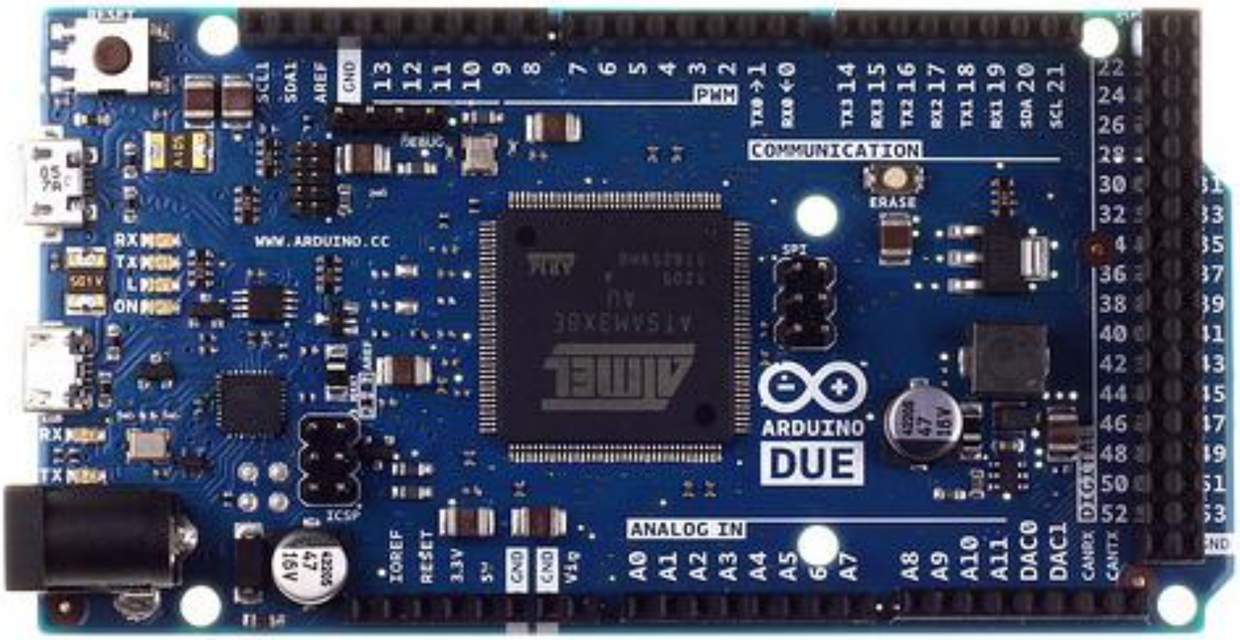
12.2 ARDUINO: Model Used is “ARDUINO DUE”

The Arduino Due is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. It is the first Arduino board based on a 32-bit ARM core microcontroller. It has 54 digital input/output pins (of which 12 can be used as PWM outputs), 12 analog inputs, 4 UARTs (hardware serial ports), a 84 MHz clock, an USB OTG capable connection, 2 DAC (digital to analog), 2 TWI, a power jack, an SPI header, a JTAG header, a reset button and an erase button. Unlike other Arduino boards, the Arduino Due board runs at 3.3V. The maximum voltage that the I/O pins can tolerate is 3.3V. Providing higher voltages, like 5V to an I/O pin could damage the board**.**

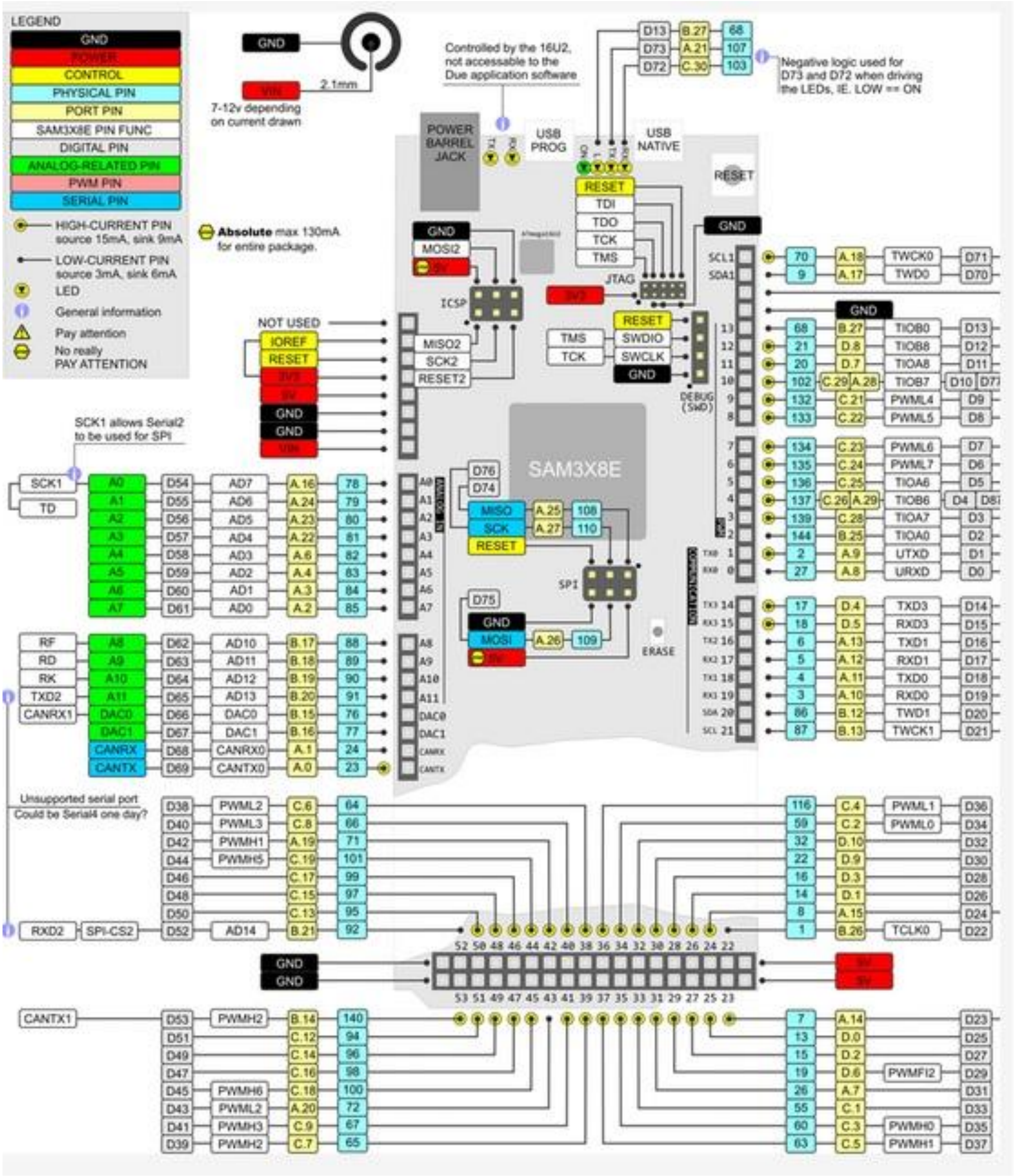
The board contains everything needed to support the microcontroller; simply connect it to a computer with a micro-USB cable or power it with a AC-to-DC adapter or battery to get started. The Due is compatible with all Arduino shields that work at 3.3V and are compliant with the 1.0 Arduino pinout.

The Due follows the 1.0 pinout:

- TWI: SDA and SCL pins that are near to the AREF pin.
- The IOREF pin which allows an attached shield with the proper configuration to adapt to the voltage provided by the board. This enables shield compatibility with a 3.3V board like the Due and AVR-based boards which operate at 5V.
- An unconnected pin, reserved for future use.



12.2.1 Pin Configuration on Arduino Due Board is as under:



After successful completion of the wiring of the Arduino Board and the XBEE module with the laptop and RS232 Serial converter, the Controlling of quadrotor via the arrow switches, is done by the following program.

09.2.2 Program

```
#include "opencv/cv.h"
#include "opencv/highgui.h"
#include<iostream>
#include <windows.h>
#include <tchar.h>
#include <stdio.h>
#include<conio.h>
using namespace std;

void PrintCommState(DCB dcb)
{
    //  Print some of the DCB structure values
    _tprintf(TEXT("\nBaudRate = %d, ByteSize = %d, Parity = %d, 
StopBits = %d\n"),
        dcb.BaudRate,
        dcb.ByteSize,
        dcb.Parity,
        dcb.StopBits
        );
}

void SerialPutc(HANDLE *hCom, char txchar)
{

BOOL bWriteRC;
static DWORD iBytesWritten;
bWriteRC = WriteFile(*hCom, &txchar, 1, &iBytesWritten,NULL);
if(!bWriteRC)
{
    printf("error");
}
//cout<<bWriteRC;
return;
}

char SerialGetc(HANDLE *hCom)
{
char rxchar;
BOOL bReadRC;
static DWORD iBytesRead;

bReadRC = ReadFile(*hCom, &rxchar, 1, &iBytesRead, NULL);
if(!bReadRC)
{
    printf("error");
}
return rxchar;
```

```
}

int _tmain(
            int argc,
            TCHAR *argv[]
           )
{
   char out, x;

   DCB dcb;
   HANDLE hCom;
   BOOL fSuccess;
   TCHAR *pcCommPort = TEXT("COM9"); //  Most systems have a
COM1 port

   //  Open a handle to the specified com port.
   hCom = CreateFile( pcCommPort,
                    GENERIC_READ | GENERIC_WRITE,
                    0,    //  must be opened with exclusive-
access
                    NULL, //  default security attributes
                    OPEN_EXISTING, //  must use OPEN_EXISTING
                    FILE_ATTRIBUTE_NORMAL,NULL//  hTemplate must
be NULL for comm devices
                    );
   if (hCom == INVALID_HANDLE_VALUE)
   {
       //  Handle the error.
       printf ("CreateFile failed with error %d.\n",
GetLastError());
       return (1);
   }
    SetupComm(hCom, 2, 128);
   //  Initialize the DCB structure.
//   SecureZeroMemory(&dcb, sizeof(DCB));
   dcb.DCBlength = sizeof(DCB);

   //  Build on the current configuration by first retrieving
all current
   //  settings.
   fSuccess = GetCommState(hCom, &dcb);


   PrintCommState(dcb);       //  Output to console

   //  Fill in some DCB values and set the com state:
   //  57,600 bps, 8 data bits, no parity, and 1 stop bit.
   dcb.BaudRate = CBR_9600;     //  baud rate
dcb.ByteSize =8;
dcb.Parity = NOPARITY;
// dcb.Parity = EVENPARITY;
dcb.StopBits = ONESTOPBIT;
//dcb.fAbortOnError = TRUE;
```

```
//dcb.fOutxCtsFlow = TRUE; // turn on CTS flow control
/*dcb.fRtsControl = RTS_CONTROL_HANDSHAKE; //
// set DSRDTR
dcb.fOutxDsrFlow = FALSE; // turn on DSR flow control
dcb.fDtrControl = DTR_CONTROL_ENABLE; //*/
   fSuccess = SetCommState(hCom, &dcb);

   if (!fSuccess)
   {
      //  Handle the error.
      printf ("SetCommState failed with error %d.\n",
GetLastError());
      return (3);
   }
   //  Get the comm config again.
   fSuccess = GetCommState(hCom, &dcb);

   if (!fSuccess)
   {
      //  Handle the error.
      printf ("GetCommState failed with error %d.\n",
GetLastError());
      return (2);
   }

   PrintCommState(dcb);       //  Output to console
/*COMMTIMEOUTS CommTimeouts;
    GetCommTimeouts (hCom, &CommTimeouts);

CommTimeouts.ReadIntervalTimeout = 5000;
CommTimeouts.ReadTotalTimeoutConstant = 5000;
CommTimeouts.ReadTotalTimeoutMultiplier = 1000;
CommTimeouts.WriteTotalTimeoutConstant = 5000;
CommTimeouts.WriteTotalTimeoutMultiplier = 1000;

SetCommTimeouts (hCom, &CommTimeouts);
PrintCommState(dcb);*/
  IplImage *src=cvCreateImage(cvSize(640,480), 8, 3);
   CvCapture* capture =cvCaptureFromCAM(CV_CAP_ANY);

   char txchar;
   HANDLE *ptr=&hCom;
   while(1)
   {
   int key,y,z,k;
       src = cvRetrieveFrame( capture );

       cvNamedWindow( "out", CV_WINDOW_AUTOSIZE );
       cvShowImage( "out", src );

       key = cvWaitKey(1);
//       cout<<"    "<<key<<"\n";
switch(key)
```

```
{
    case 2490368:               //up
    printf("up \n");
    SerialPutc(ptr,'a');
break;

case 2424832:                 //left
    printf("left \n");
    SerialPutc(ptr,'d');
break;

case 2555904:                    // right
    printf("right \n");
    SerialPutc(ptr,'c');
break;

case 2621440:                   //down
    printf("down \n");
    SerialPutc(ptr,'b');
break;

case 32:                   //kill
    printf("down \n");
    SerialPutc(ptr,'s');
break;

}
x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);
k=x+y+z-23;
if(k==-23);
printf(" <_arm angle= %d_ >",x+y+z-23);
Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);
k=x+y+z-23;
if(k==-23);
printf("<_base angle=%d>",x+y+z-23);
Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);
k=x+y+z-23;
if(k==-23);
printf("<_upper arm =%d_>",x+y+z-23);
Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
```

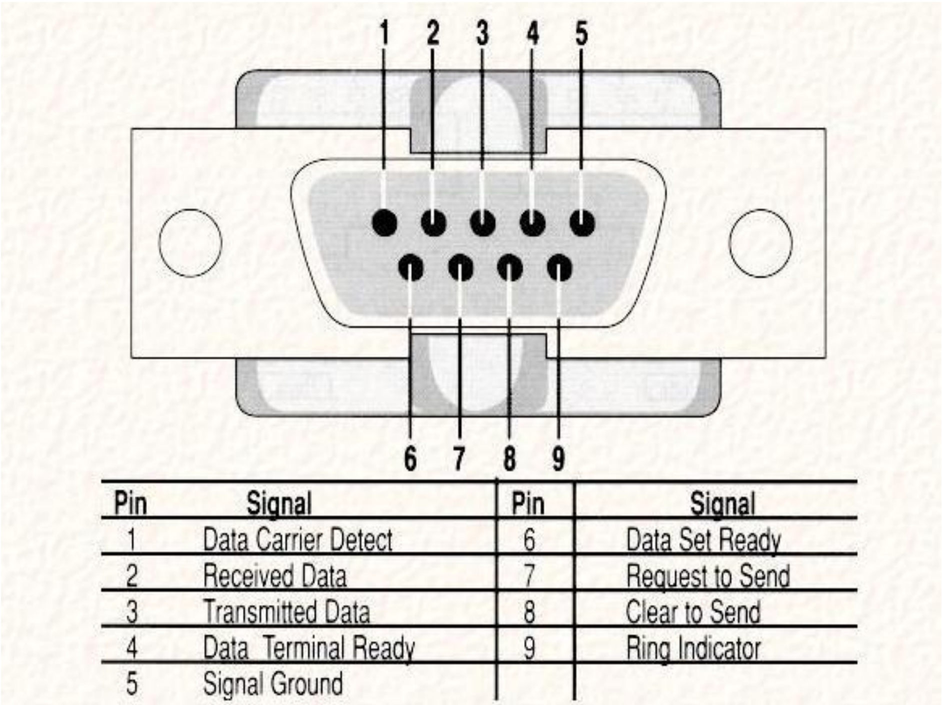
```
z=SerialGetc(ptr);
k=x+y+z-23;
if(k!=-23);
printf("<_hand angle =%d_ >",x+y+z-23);

Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);
k=x+y+z-23;
if(k!=-23);
printf("<_finger1=%d_>",x+y+z-23);
Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);

k=x+y+z-23;
if(k!=-23);
printf("<accleratometer =%d_>",x+y+z-23);
Sleep(2);

x=SerialGetc(ptr);
y=SerialGetc(ptr);
z=SerialGetc(ptr);
k=x+y+z-23;
if(k!=-23);
printf("pressure sensor=%d_ >\n ",x+y+z-23);

Sleep(2);
       cvGrabFrame( capture );

   }
   _tprintf (TEXT("Serial port %s successfully
reconfigured.\n"), pcCommPort);

cvDestroyAllWindows();
cvReleaseCapture( &capture );

}
```

12.2.3 The Arduino on the quadrotor controls the servo motor using the following Code. The Signals to the servo motor is sent with an attempt to minimise the turbulence. The signal is sent to the BLDC ESC which in turn provides power to the servo motor.

```
#include <Servo.h>

Servo servof;        //declaration of servo
Servo servob;

Servo servor;
Servo servol;


void setup() {
  // initialize serial communication:
   servof.attach(6);           // pin declartion of servo
   servob.attach(9);
   servor.attach(10);
   servol.attach(11);

  Serial.begin(9600);
   // initialize the LED pins:

}

void loop() {
  // read the sensor:
  int f=1000,b=1000,r=1000,l=1000, res=10,x=0, y=0,g=0;
  char fc, bc, rc, lc, xc,yc,gc, input=100;

  fc=f/10;
  bc=b/10;
  rc=r/10;
  lc=l/10;
  xc=x/5;
  yc=y/5;
  gc=g/10;
  {
  //   input = Serial.read();
     Serial.println(fc);
     Serial.println(bc);
     Serial.println(rc);
     Serial.println(lc);
     Serial.println(xc);
     Serial.println(yc);
     Serial.println(gc);
    // do something different depending on the character
received.
    // The switch statement expects single number values for
each case;
  // in this exmaple, though, you're using single quotes to tell
```

```
    // the controller to get the ASCII value for the character.
For
    // example 'a' = 97, 'b' = 98, and so forth:
{
servof.writeMicroseconds(f);              // initialise
servob.writeMicroseconds(b);
servor.writeMicroseconds(r);
servol.writeMicroseconds(l);
  while(1)
  {delay(200);
input = Serial.read();
  x=analogRead(A0);       delay(5);
  y=analogRead(A1);         delay(5);
  g=analogRead(A2);       delay(5);
  Serial.println(fc=f/10);     delay(5);
     Serial.println(bc=b/10);   delay(5);
     Serial.println(rc=r/10);    delay(5);
     Serial.println(lc=l/10);      delay(5);
     Serial.println(xc=x/5);     delay(5);
     Serial.println(yc=y/5);      delay(5);
     Serial.println(gc=g/10);     delay(5);

    switch (input)
    {
    case 'a':                                 //up
      servof.writeMicroseconds(f=f+res);
      servob.writeMicroseconds(b=b+res);
      servor.writeMicroseconds(r=r+res);
     servol.writeMicroseconds(l=l+res);
    // Serial.println('a');
      break;
    case 'b':
if (f>0)    // down
   {
      servof.writeMicroseconds(f=f-res);
      if(b>0)
      servob.writeMicroseconds(b=b-res);
      if(r>0)
      servor.writeMicroseconds(r=r-res);
      if(l>0)
     servol.writeMicroseconds(l=l-res);
    // Serial.println('b');
   }

      break;
    case 'c':
    //forward

      servof.writeMicroseconds(f=f+res);
      servob.writeMicroseconds(b=b+res);
    //  Serial.println('c');

      break;
```

```
        case 'd':                                 //backwrd
          servor.writeMicroseconds(f=f+res);
          if(b>0)
         servol.writeMicroseconds(b=b+res);
        //  Serial.println('d');
          break;
        case 'e':
    if(r>0)// right
          servor.writeMicroseconds(r=r-res);
         servol.writeMicroseconds(l=l+res);
        //  Serial.println('e');
          break;
        case 'f':                                  // right
          servor.writeMicroseconds(r=r+res);
          if(l>0)
         servol.writeMicroseconds(l=l-res);

        //  Serial.println('f');
          break;
        case 's':                                  // left
          servof.writeMicroseconds(f=1000);
          servob.writeMicroseconds(b=1000);
          servor.writeMicroseconds(r=1000);
         servol.writeMicroseconds(l=1000);
              //  Serial.println('s');
          break;
           } }
    }      } }
```



Pin	Signal	Pin	Signal
1	Data Carrier Detect	6	Data Set Ready
2	Received Data	7	Request to Send
3	Transmitted Data	8	Clear to Send
4	Data Terminal Ready	9	Ring Indicator
5	Signal Ground		

PIN Configuration of a RS232: USB to Serial Converter

13. Analysis and Optimisation of time of Flight

Now as we all know that a quadrotor has a maximum flight time of 10-15 mins using a 3 Cell, 11.1V, 2000mAh, 20C Lithium Polymer Cell. Therefore we take a dig at the causes for minimal flight time and its subsequent precautions.

As per the Archimedes principle, the up thrust on a body immersed partially or wholly in a fluid is equal to the weight of the liqud displaced by the part of body inside the fluid. In this context, the up thrust experienced by the quadrotor due to the propellers in actions, is the weight of air displaced by the propellers.

Again the weight of air displaced by the propellers depends on the following factors:

1. Design of propeller and its efficiency
2. Motor Speed
3. Density of air

We need to design the quadrotor such that with minimum defined speed of motor (thus low power exhausted from battery), the propeller must be generating enough thrust to lift the body into the air. Thus the design and configuration of propellers play a very imp role in the scenario.

13.1 Propeller Design in a Quadrotor:

Assuming the quadrotor's maximum weight is 9.81N(1 kg) and that we have four propellers, it is mandatory that each propeller is able to provide at least 2.45 N (1/4 the quadrotor weight) in order to achieve lift-off. Taking this data into consideration leads us to wonder about the minimum propeller rotational speed involved, as well as the magnitude of the power required for flight.

The typical behaviour of a propeller can be defined by three major parameters:

- Thrust Coefficient
- Power Coefficient
- Propeller Radius

These parameters allow calculation of propeller's thrust and Power. **B**oth thrust and power increase greatly with propeller's diameter. If the diameter is big enough, then it should be possible to get sufficient thrust while demanding low rotational speed of the propeller. Consequently, the motor driving the propeller will have lower power consumption, giving the quadrotor higher flight autonomy.

The propellers used in the rotors are fixed pitch, signifying that the pitch angle *β*, sometimes referred to as the blade angle, remains fixed. However, this should not be confused with constant pitch, as the pitch can vary along the length of the propeller blade but cannot be adjusted. Propeller geometry can be complex, where the chord length *c* and airfoil profiles vary along the length of the blade. The pitch angle determines the pitch of the propeller *p*, which is the distance that the propeller moves through the air for each revolution, much like a screw. This is why propellers are sometimes referred to as 'air screws'. This relationship can be described as,

$$p = 2\pi r \tan\beta$$

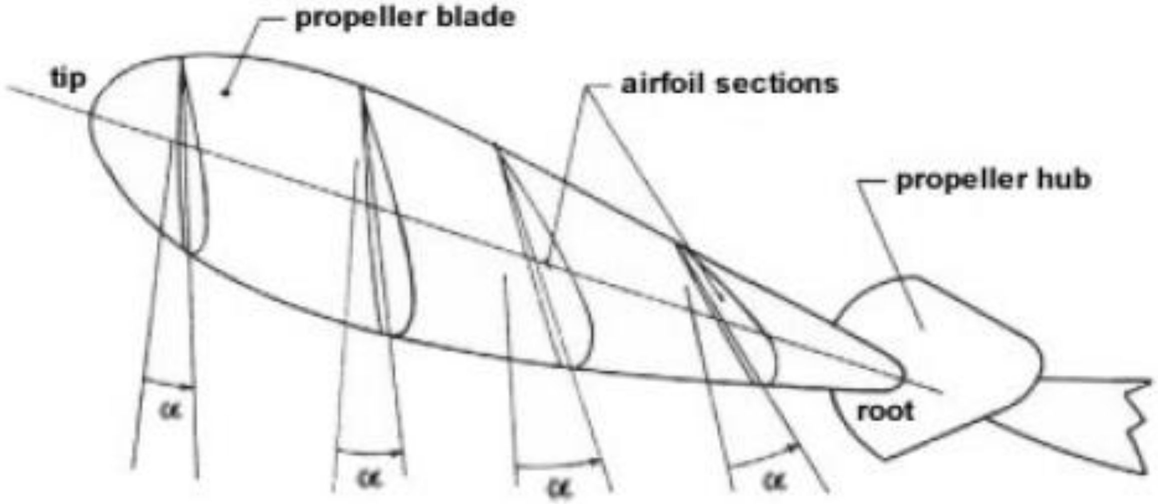
Where *r* is the distance along the blade where the specificpitch angle exists. Because of the variation that exists, a ratio is commonly used known as the pitch diameter ratio,

$$p/D = \pi x \tan\beta$$

Where *D* is the diameter of the propeller and *x* is therelative radios of the blade section and may be represented as,

$$x = r/R$$

Because of the variation of *β* and *c* throughout the lengthof the radius, the angle of attack *α* is also varied. This can be shown graphically



An infinitesimal cross section *dr*, a length *r* away from the centre of the propeller was considered. The dashed line in the figure represents the zero lift line. The velocity *VE* is the induced air velocity and enters the blade at an angle *α* to the zero lift line. The velocity *V* is the advance velocity of the propeller and the velocity ωr is the velocity due to rotation. The angle *Φ* is the angle of resultant flow. The dimensionless co-efficient of lift
CL is dependent on angles *α, β* and *Φ* and the co-efficient of drag *CD* is a function of *CL* and Mach and Reynolds numbers. The lift *dL* generated is always orthogonal to the line of zerolift. The thrust *dT*, which is the effective upward force perpendicular to the plane of rotation, is a component of *dL*. The drag *dD* is the force acting adjacent to the air foil and the force *dFQ* is the component of *dD* which creates the
drag moment *dQ* where,

$$dQ = dF_Q r$$

The local lift and drag may be expressed as,

$$dL = \frac{1}{2}\rho V_E^2 c C_L dr$$

$$dD = \frac{1}{2}\rho V_E^2 c C_D dr$$

Where, ρ is the density of air. Vortex theory was analysed to determine the thrust and drag moment. In the same manner in which a wing works, the aerodynamic lift on a propeller blade can be related to a bound circulation Γ around the blade,

This bound circulation may be expressed as,

$$\Gamma = \frac{1}{2} c C_L V_E$$

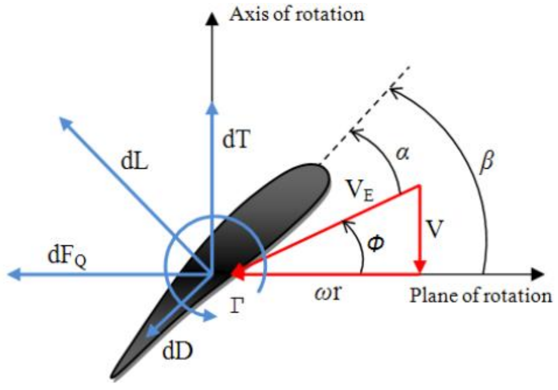
Using the change in bound circulation, the local thrust and drag moments are,

$$dT = \rho(\Omega - \omega) r d\Gamma$$

$$dQ = \rho(V - v) r d\Gamma$$

Where, P and V are the global rotational and advance velocities respectively. From this, the local efficiency of the propeller can be found,

$$\eta_{local} = \frac{VdT}{\Omega dQ}$$



To determine the overall efficiency of the propeller, a ratio of the product of the thrust and advance velocity and the power P must be found.

$$\eta = \frac{TV}{P}$$

However, the thrust and power may be represented as

$$T = \rho C_T D^4 n^2$$

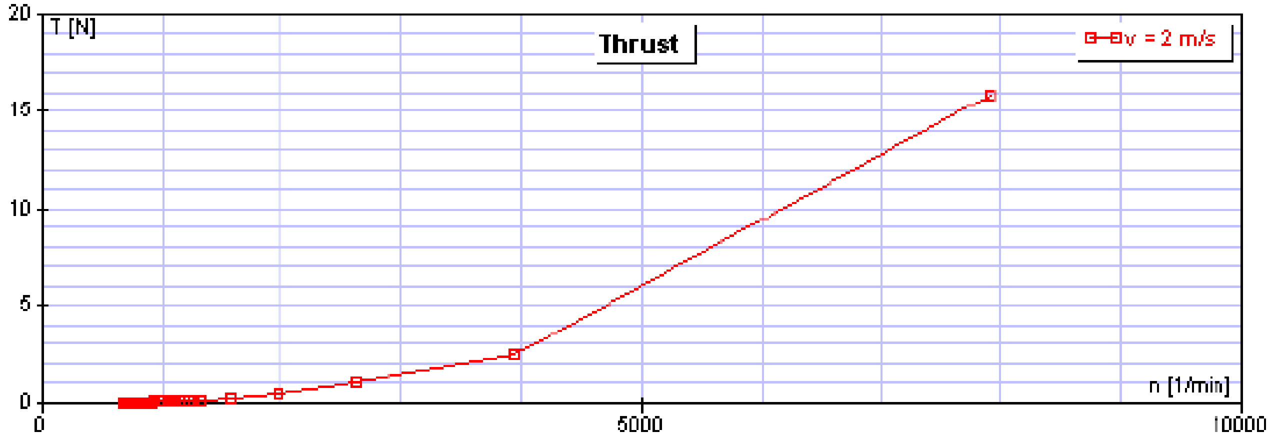
$$P = \rho C_P D^5 n^3$$

It must be noted that *D* here refers to the rotor diameterand not drag. From this, the efficiency may be represented as

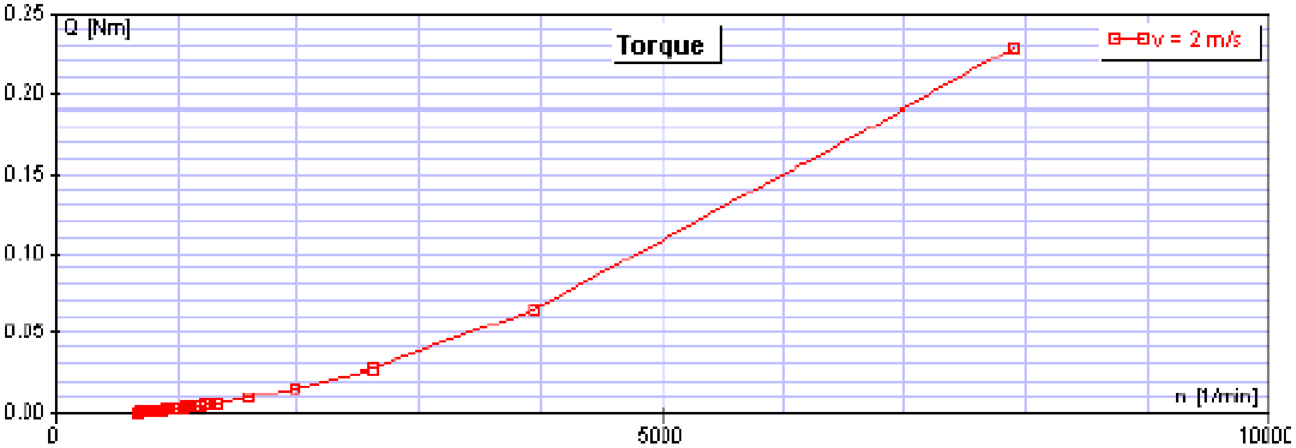
$$\eta = \frac{V}{nD}\frac{C_T}{C_P}$$

The velocity ratio in this expression is known as the advance ratio *J*,

$$J = \frac{V}{nD}$$



: Graph of thrust VS rotor speed



: Graph of drag moment VS rotor speed

And again to thrust, we have the following formulae:

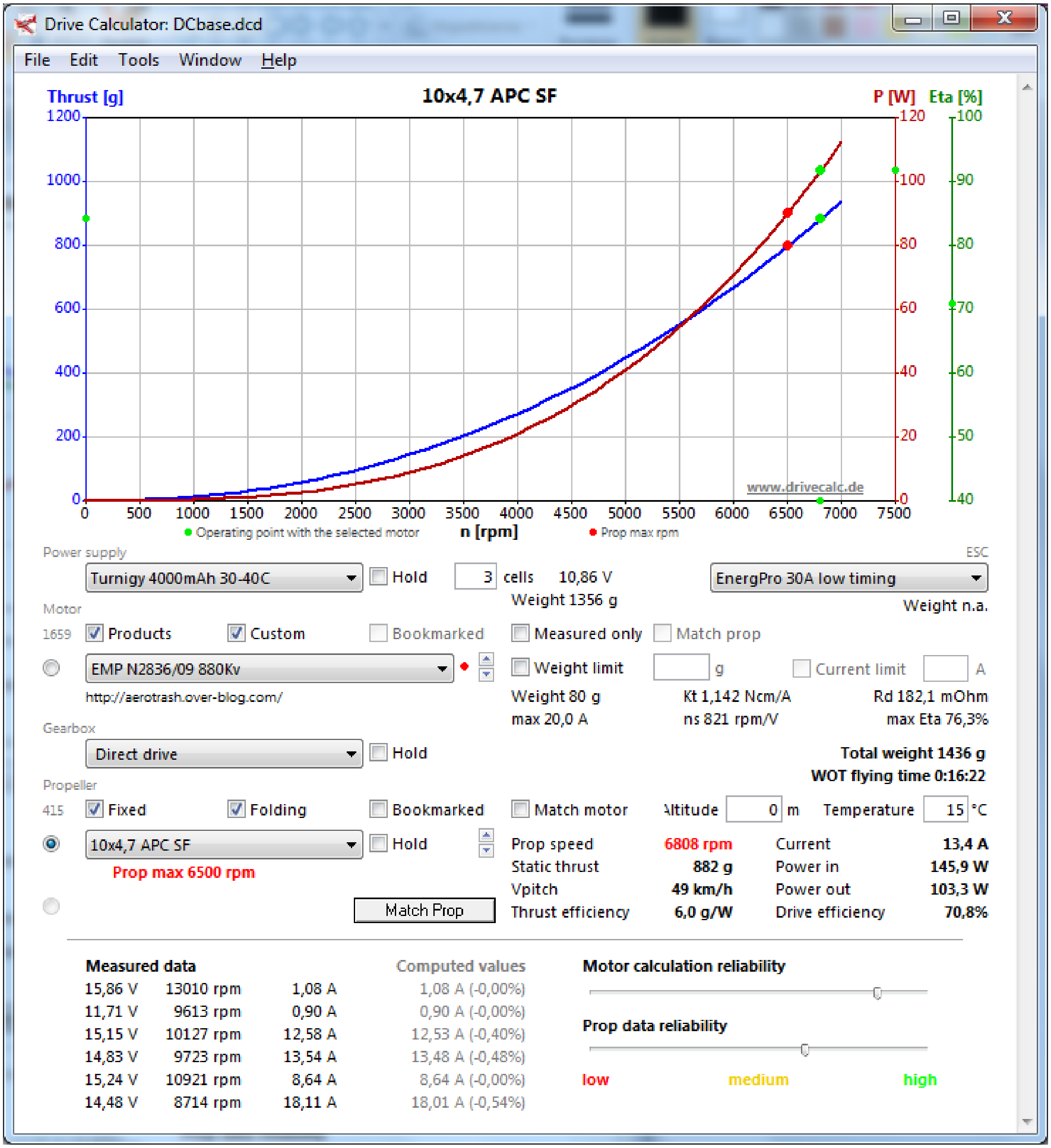
$F_T(RPS)=C_T\rho n_2D_4$,

Where: $F_T = Thrust$, $\rho[_{slugsft_3}]=0.00238$ - air density, $n[RPS]$ - prop angular speed, $D[ft]=$1012 - prop diameter. For calculating torque, the below formula must be used:

$\tau(RPS)=CP\rho n2D52\pi$.

Now the following virtual simulation is done in order to improve flight time by making optimal changes in propeller design.

Snapshot is attached below.



Power supply

Turnigy 4000mAh 30-40C □ Hold 3 cells 10,86 V

Weight 1356 g

ESC

EnergPro 30A low timing

Weight n.a.

Motor

1659 ☑ Products ☑ Custom □ Bookmarked □ Measured only □ Match prop

○ EMP N2836/09 880Kv □ Weight limit g □ Current limit A

http://aerotrash.over-blog.com/

Weight 80 g	Kt 1,142 Ncm/A	Rd 182,1 mOhm
max 20,0 A	ns 821 rpm/V	max Eta 76,3%

Gearbox

Direct drive □ Hold

Total weight 1436 g

WOT flying time 0:16:22

Propeller

415 ☑ Fixed ☑ Folding □ Bookmarked □ Match motor Altitude 0 m Temperature 15 °C

● 10x4,7 APC SF □ Hold

Prop max 6500 rpm

Prop speed	6808 rpm	Current	13,4 A
Static thrust	882 g	Power in	145,9 W
Vpitch	49 km/h	Power out	103,3 W
Thrust efficiency	6,0 g/W	Drive efficiency	70,8%

Measured data			Computed values
15,86 V	13010 rpm	1,08 A	1,08 A (-0,00%)
11,71 V	9613 rpm	0,90 A	0,90 A (-0,00%)
15,15 V	10127 rpm	12,58 A	12,53 A (-0,40%)
14,83 V	9723 rpm	13,54 A	13,48 A (-0,48%)
15,24 V	10921 rpm	8,64 A	8,64 A (-0,00%)
14,48 V	8714 rpm	18,11 A	18,01 A (-0,54%)

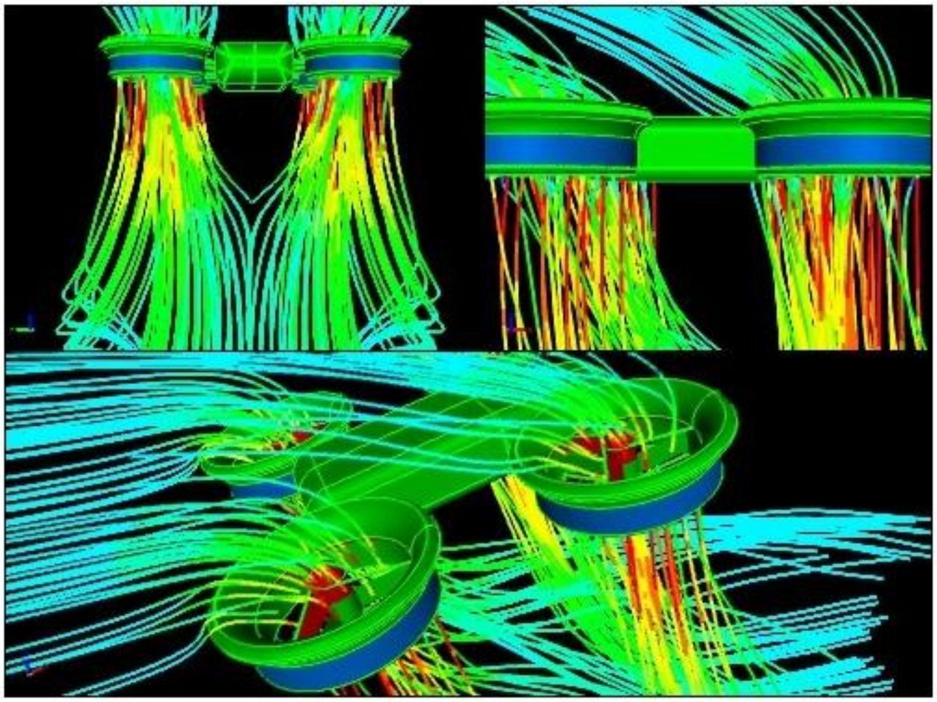
Motor calculation reliability

Prop data reliability

We can see that a propeller will have to achieve approximately 412 rad/s, which is equivalent to 3934 revolutions per minute, to provide the minimum 2.45 N required for lift-off. The respective propeller power is 26W.

As we can see, the total flight time has increased from 10-12 Minutes to 16:22 Minutes. With minor errors creeping in, i.e. by a percent of 5%, the flight time is still much higher. The same analysis can also be done using a Moving reference Frame inivolving Computational Fluid Dynamics modelling technique.

A Moving Reference Frame (MRF) is a relatively simple, robust, and efficient steady-state, Computational Fluid Dynamics (CFD) modeling technique to simulate rotating machinery. For example, the rotors on a quadcopter can be modeled with MRFs.



MRF CFD Simulation of a Quadcopter in Flight
Shows streamlines colored by velocity magnitude

The quadrotor (symmetrical half model) geometry was created in Caedium Professional. The CFD simulation was performed using the incompressible, steady-state RANS solver, with multiple MRF, and the k-omega SST turbulence model

13.2 Optimal Environment Conditions for enhanced flight time:

Apart from that, the density of air also very important as more the density of air, more will be the weight of air displaced and thus the power consumption will decrease. The density of air depends on the following factors again:

1. Temperature of the air
2. Humidity
3. Altitude
4. Wind Flow

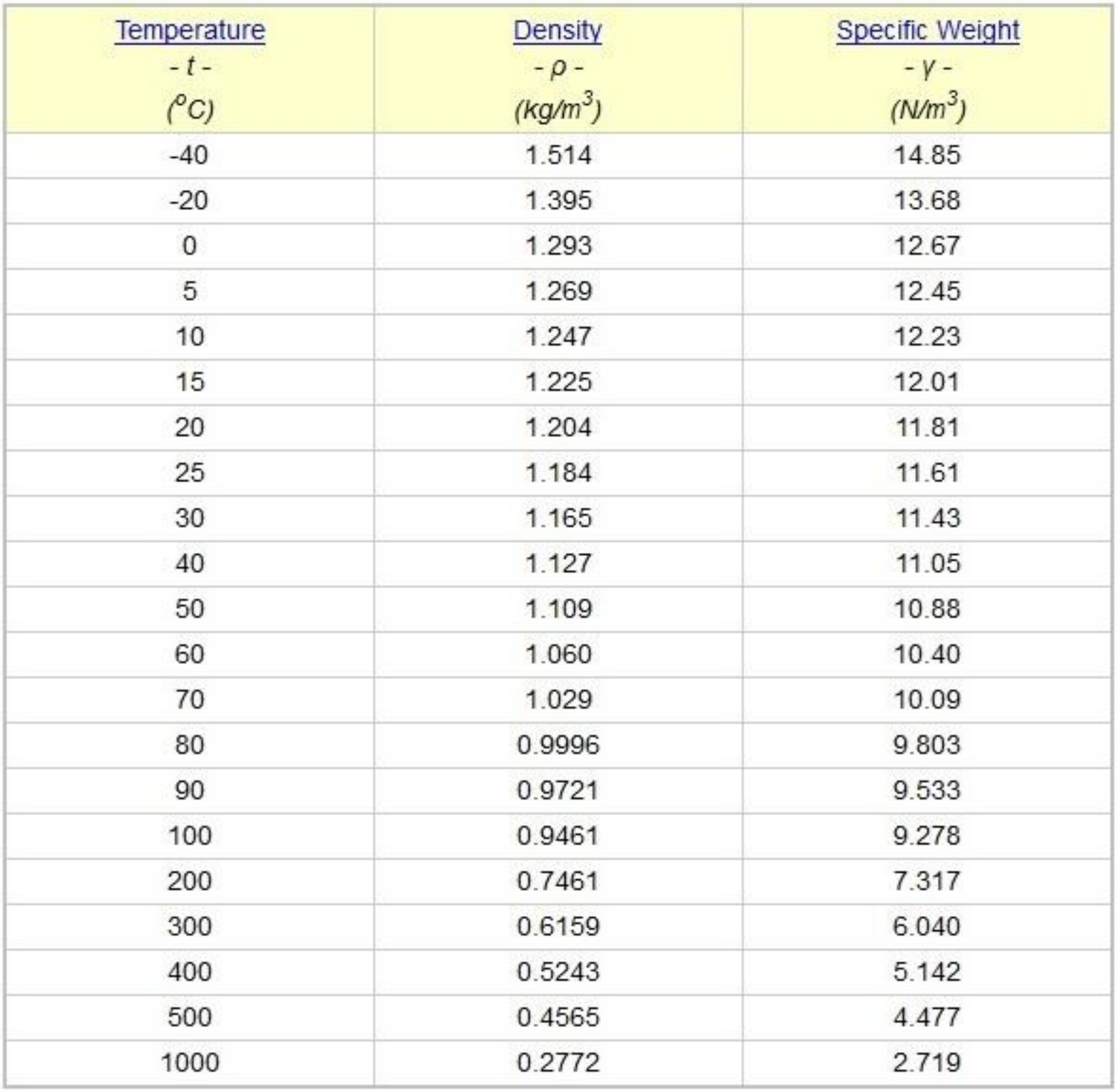
We have done a little research into the above mentioned factors to finally obtain the optimum environment conditions and propeller design in order to enhance the flight time.

Density Of Air and other factors affecting it:

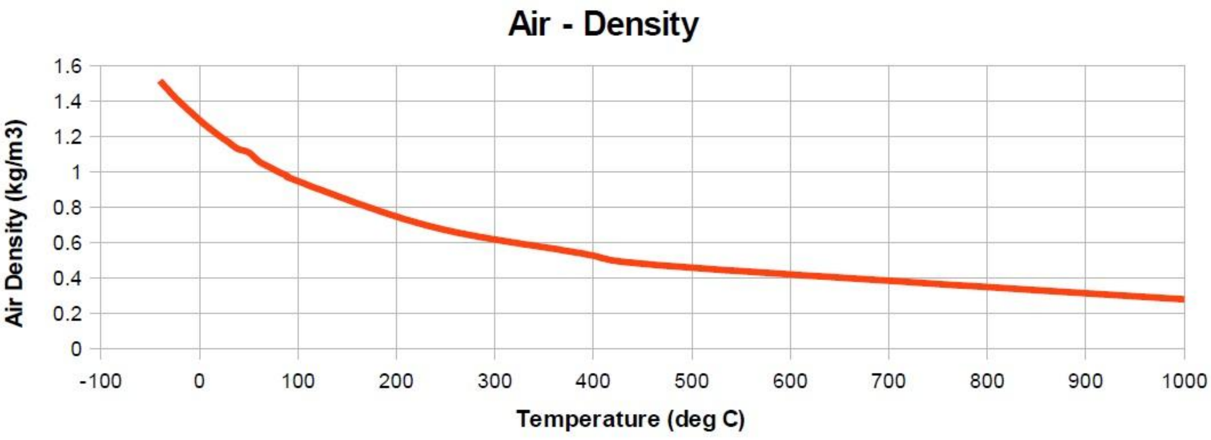
The **density of air**, is the mass per unit volume of Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature or humidity.

We look into each of the factors one after another.

13.2.1 Temperature and Density



Temperature - *t* - *(^oC)*	Density - *ρ* - *(kg/m^3)*	Specific Weight - *γ* - *(N/m^3)*
-40	1.514	14.85
-20	1.395	13.68
0	1.293	12.67
5	1.269	12.45
10	1.247	12.23
15	1.225	12.01
20	1.204	11.81
25	1.184	11.61
30	1.165	11.43
40	1.127	11.05
50	1.109	10.88
60	1.060	10.40
70	1.029	10.09
80	0.9996	9.803
90	0.9721	9.533
100	0.9461	9.278
200	0.7461	7.317
300	0.6159	6.040
400	0.5243	5.142
500	0.4565	4.477
1000	0.2772	2.719



The density of dry air can be calculated using the ideal gas law, expressed as a function of temperature and pressure:

$$\rho = \frac{p}{R_{\text{specific}} T}$$

where:

$\rho =$air density
$p =$absolute pressure
$T =$absolute temperature
$R_{\text{specific}} =$specific gas constant for dry air

The specific gas constant for dry air is 287.058 J/(kg·K) in SI units. This quantity may vary slightly depending on the molecular composition of air at a particular location.

At IUPAC standard temperature and pressure (0 °C and 100 kPa), dry air has a density of 1.2754 kg/m^3. (At 20 °C and 101.325 kPa, dry air has a density of 1.2041 kg/m^3.)

13.2.2 Humidity (Water Vapor)

The addition of water vapor to air (making the air humid) reduces the density of the air, which may at first appear counter-intuitive. This occurs because the molar mass of water (18 g/mol) is less than the molar mass of dry air[note 1] (around 29 g/mol). For any gas, at a given temperature and pressure, the number of molecules present is constant for a particular volume (see Avogadro's Law). So when water molecules (water vapor) are added to a given volume of air, the dry air molecules must decrease by the same number, to keep the pressure or temperature from increasing. Hence the mass per unit volume of the gas (its density) decreases.

The density of humid air may be calculated as a mixture of ideal gases. In this case, the partial pressure of water vapor is known as the vapor pressure. Using this method, error in the density calculation is less than 0.2% in the range of −10 °C to 50 °C. The density of humid air is found by:

$$\rho_{\text{humid air}} = \frac{p_d}{R_d T} + \frac{p_v}{R_v T} = \frac{p_d M_d + p_v M_v}{RT}$$

where:

- $\rho_{\text{humid air}} =$Density of the humid air (kg/m³)
- $p_d =$Partial pressure of dry air (Pa)
- $R_d =$Specific gas constant for dry air, 287.058 J/(kg·K)
- $T =$Temperature (K)
- $p_v =$Pressure of water vapor (Pa)
- $R_v =$Specific gas constant for water vapor, 461.495 J/(kg·K)
- $M_d =$Molar mass of dry air, 0.028964 kg/mol
- $M_v =$Molar mass of water vapor, 0.018016 kg/mol
- $R =$Universal gas constant, 8.314 J/(K·mol)

13.2.3 Altitude

Standard Atmosphere: $\boldsymbol{p_0}$=101.325 kPa, $\boldsymbol{T_0}$=288.15 K, ρ=1.225 [[kg/m^3]]

To calculate the density of air as a function of altitude, one requires additional parameters. They are listed below, along with their values according to the International Standard Atmosphere, using for calculation the universal gas constant instead of the air specific constant:

- $p_0 =$sea level standard atmospheric pressure, 101.325 kPa
- $T_0 =$sea level standard temperature, 288.15 K
- $g =$earth-surface gravitational acceleration, 9.80665 m/s^2
- $L =$temperature lapse rate, 0.0065 K/m
- $R =$ideal (universal) gas constant, 8.31447 J/(mol·K)
- $M =$molar mass of dry air, 0.0289644 kg/mol

Temperature at altitude $h$meters above sea level is approximated by the following formula (only valid inside the troposphere):

$$T = T_0 - Lh$$

The pressure at altitude h is given by:

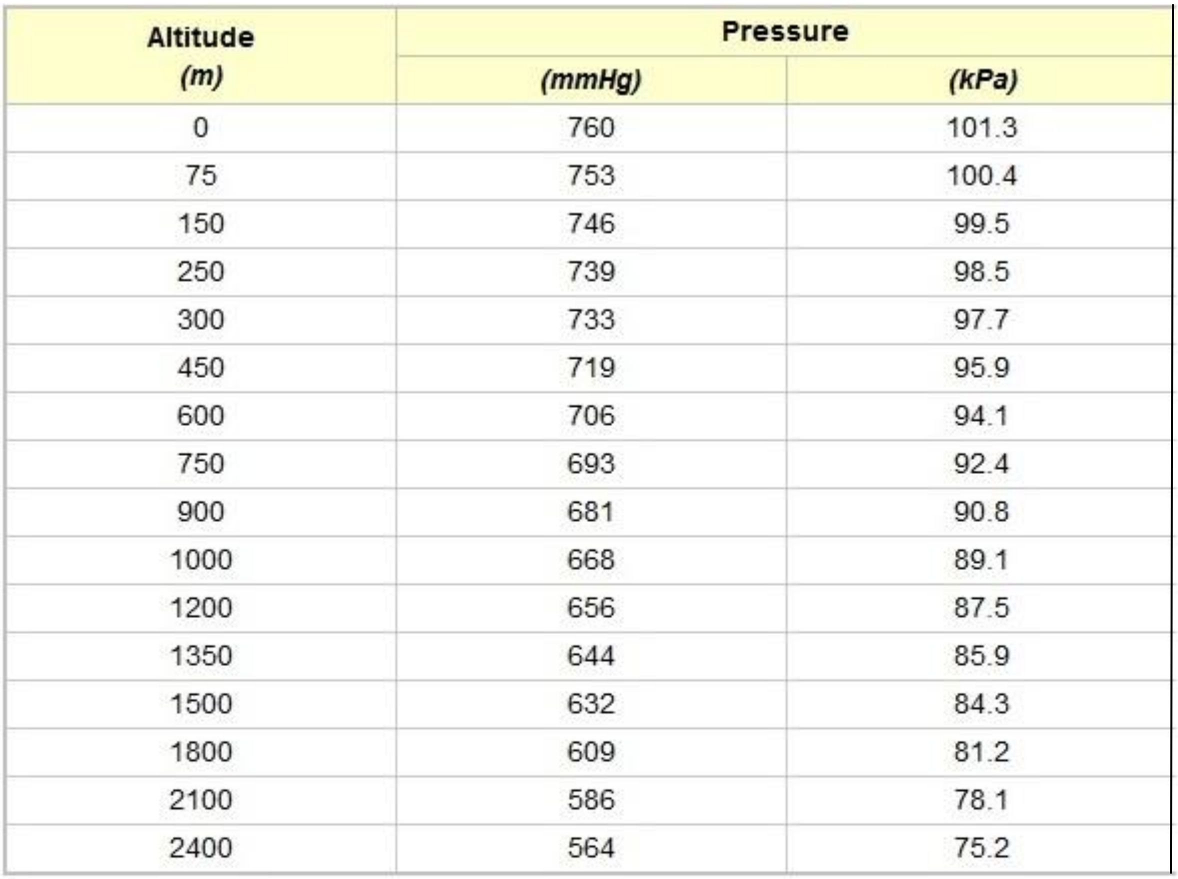
$$p = p_0 \left(1 - \frac{Lh}{T_0}\right)^{\frac{gM}{RL}}$$

Density can then be calculated according to a molar form of the ideal gas law:

$$\rho = \frac{pM}{RT}$$

where:

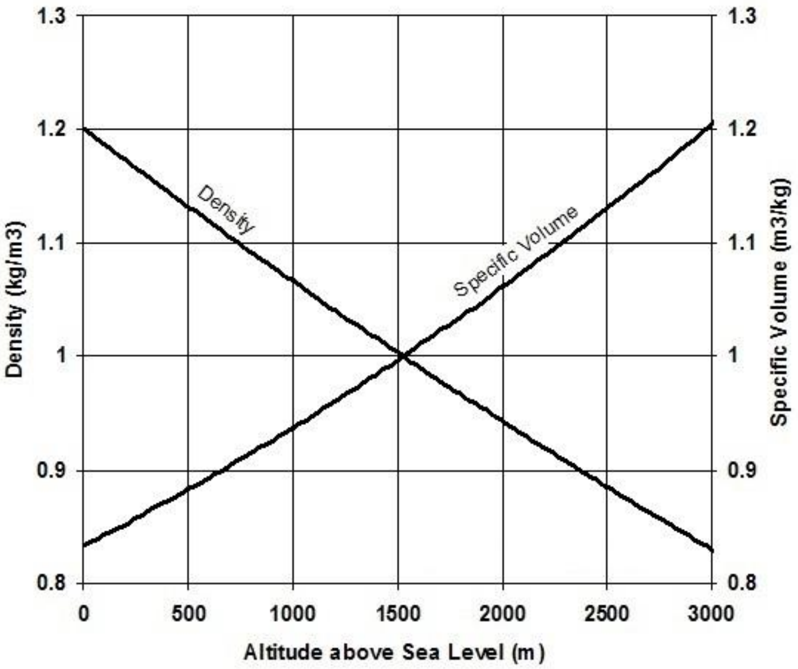
- $M =$molar mass
- $R =$ideal gas constant
- $T =$absolute temperature
- $p =$absolute pressure must be in Pa and not the kPa above.



Altitude	**Pressure**	
(m)	***(mmHg)***	***(kPa)***
0	760	101.3
75	753	100.4
150	746	99.5
250	739	98.5
300	733	97.7
450	719	95.9
600	706	94.1
750	693	92.4
900	681	90.8
1000	668	89.1
1200	656	87.5
1350	644	85.9
1500	632	84.3
1800	609	81.2
2100	586	78.1
2400	564	75.2

Altitude and Air Density

Air density and specific volume as functions of altitude above sea level can be indicated as in the diagrams below:



13.2.4 Wind Flow

Wind Flow is a very important aspect that must be taken into consideration before flying a quadrotor. Even a minimal wind velocity can cause severe turbulence in the flight of the Quadrotor. The Quadrotor is known for its non stability and yet is used as research purposes taking into consideration its mechanical simplicity and other advantages. And in order to balance the Quadrotor and get it stable even in the presence of medium/high wind velocity, 4 PID controllers have to be used for each of the following disturbances and their gain simultaneously.

- Pitch
- Roll
- Yaw
- throttle

But that would have additional disadvantages in the system such as High power loss, Low flight time, Low payload. Apart from that, the chances of crash increases rapidly in case of high wind velocity.

13.3 ANALYSIS REPORT

- For a Quadrotor with constant RPM of Servomotor, the height of Quadrotor differs widely in different weather. With, Maximum height in winter due to high air density and low temperature, and minimum height in summer, the difference in the height of the Quadrotor is directly dependent on the temperature and specific weight of air.
- It is advised not to fly the Quadrotor in Autumn season or any weather involving medium or high wind velocity i.e V>25 Miles /Hr. The Quadrotor might crash or go out of control due to excessive unwanted turbulence.
- The design of propellers plays a most important part for deciding the time of flight. The larger the diameter of propeller, the more is the upthrust and so less is the power exhausted from battery for motor RPM.
- In humid conditions or for the Quadrotor to fly above water bodies, the flight time decreases by 30-40% keeping in account the low density of air.
- The higher the Quadrotor flies, the less is the time of flight.
- The propellers must be surrounded with a protective ring in order to avoid disturbances caused due to change in direction of wind flow abruptly.

So in total, for maximum time of flight, the height of the flight of the Quadrotor should be kept as low as possible with maximum diameter of propellers, keeping in mind the total size of the vehicle. It should be avoided to fly the Quadrotor above water bodies and in humid or windy weather. Since the range of XBEE Pro wireless module is within 1.6Km in line of sight RF technique, the Quadrotor must be operated within the said range.

14. AREAS OF IMPLEMENTATION

14.1 Research platform:

Quadrotors are a useful tool for university researchers to test and evaluate new ideas in a number of different fields, including flight control theory, navigation, real time systems and robotics. In recent years many universities have shown “Quadrotors” performing increasingly complex aerial manoeuvres. Swarms of “Quadrotors” can hover in mid-air, in formation, autonomously perform complex flying routines such as flips, darting through hula-hoops and organise themselves to fly through windows as a group. There are numerous advantages for using “Quadrotor”s as versatile test platforms. They are relatively cheap, available in a variety of sizes and their simple mechanical design means that they can be built and maintained by amateurs. Due to the multi-disciplinary nature of operating a “Quadrotor”, academics from a number of fields need to work together in order to make significant improvements to the way Quadrotor’s perform. “Quadrotor” projects are typically collaborations between computer science, electronics engineering and mechanical engineering specialists.

Because they are so manoeuvrable, “Quadrotors” could be useful in all kinds of situations and environments. “Quadrotors” capable of autonomous flight could help remove the need for people to put themselves in any number of dangerous positions. This is a prime reason that research interest has been increasing over the years.

14.2 Military and law enforcement:

“Quadrotor” unmanned aerial vehicles are used for surveillance and reconnaissance by military and law enforcement agencies, as well as search and rescue missions in urban environments. One such example is the Aeryon Scout, created by Canadian company Aeryon Labs, which is a small UAV that can quietly hover in place and use a camera to observe people and objects on the ground.

(The RQ-7 Shadow is capable of delivering a 20 lb (9.1 kg) "Quick-MEDS" canister to front-line troops.)

Beyond the military applications of UAVs with which "drones" became most associated, numerous civil aviation uses have been developed, including aerial surveying of crops, acrobatic aerial footage in filmmaking, search and rescue operations, inspecting power lines and pipelines, and counting wildlife, with manufacturers rebranding the technology as "unmanned aerial systems" (UASs) in preference over "drones."

14.3 Commercial:

The largest use of “Quadrotor” has been in the field of aerial imagery although, In the USA, it is currently illegal to use remote controlled vehicles for commercial purposes. “Quadrotor” UAVs are suitable for this job because of their autonomous nature and huge cost savings. Capturing aerial imagery with a “Quadrotor” is as simple as programming GPS coordinates and hitting the go button. Using on-board cameras, users have the option of being streamed live to the ground. Many companies have used this for real estate photography to industrial systems inspection. Various organizations are taking advantage of the Quadrotor’s closed-circuit television capabilities and ability to provide an eye in the sky to the action below. Recently Amazon has come up with an idea to drop parcels using multi Rotor aircraft thus decreasing manpower and saving a lot of expenditure.

14.4 Remote sensing:

UAV remote sensing functions include electromagnetic spectrum sensors, gamma ray sensors, biological sensors, and chemical sensors. A UAV's electromagnetic sensors typically include visual spectrum, infrared, or near infrared cameras as well as radar systems. Other electromagnetic wave detectors such as microwave and ultraviolet spectrum sensors may also be used but are uncommon. Biological sensors are sensors capable of detecting the airborne presence of various microorganisms and other biological factors. Chemical sensors use laser spectroscopy to analyze the concentrations of each element in the air.

14.5 Commercial aerial surveillance:

Aerial surveillance of large areas is made possible with low cost UAV systems. Surveillance applications include livestock monitoring, wildfire mapping, pipeline security, home security, road patrol, and anti-piracy. The trend for the use of UAV technology in commercial aerial surveillance is expanding rapidly with increased development of automated object detection approaches.

14.6 Domestic policing:

UAVs are increasingly used for domestic police work in Canada and the United States: a dozen US police forces had applied for UAV permits by March 2013. Texas politician and commentator Jim Hightower has warned about potential privacy abuses from aerial surveillance. In February 2013, Seattle Mayor Michael McGinn responded to protests by scrapping the Seattle Police Department's plan to deploy UAVs.

14.7 Oil, gas and mineral exploration and production:

UAVs can be used to perform geophysical surveys, in particular geomagnetic surveys where the processed measurements of the Earth's differential magnetic field strength are used to calculate the nature of the underlying magnetic rock structure. A knowledge of the underlying rock structure helps trained geophysicists to predict the location of mineral deposits. The production side of oil and gas exploration and production entails the monitoring of the integrity of oil and gas pipelines and related installations. For above-ground pipelines, this monitoring activity could be performed using digital cameras mounted on one or more UAVs. The InView Unmanned Aircraft System is an example of a UAV developed for use in oil, gas, and mineral exploration and production activities.

14.8 Transport:

UAVs can transport goods using various means based on the configuration of the UAV itself. Most payloads are stored in an internal payload bay somewhere in the airframe. For many helicopter configurations, external payloads can be tethered to the bottom of the airframe. With fixed-wing UAVs, payloads can also be attached to the airframe, but aerodynamics of the aircraft with the payload must be assessed. For such situations, payloads are often enclosed in aerodynamic pods for transport.

14.9 Scientific Research:

Unmanned aircraft are especially useful in penetrating areas that may be too dangerous for manned aircraft. The National Oceanic and Atmospheric Administration (NOAA) began utilizing the Aerosonde unmanned aircraft system in 2006 as a hurricane hunter. AAI

Corporation subsidiary Aerosonde Pty Ltd. of Victoria, Australia, designs and manufactures the 35-pound system, which can fly into a hurricane and communicate near-real-time data directly to the National Hurricane Center in Florida. Beyond the standard barometric pressure and temperature data typically culled from manned hurricane hunters, the Aerosonde system provides measurements far closer to the water's surface than previously captured. Further applications for unmanned aircraft can be explored once solutions have been developed for their accommodation within national airspace, an issue currently under discussion by the Federal Aviation Administration. UAVSI, the UK manufacturer, also produces a variant of their Vigilant light UAS (20 kg) designed specifically for scientific research in severe climates, such as the AntarctiC.

There have also been experiments with using UAVs as a construction and artwork tool at locations such as the ETH Zurich.

14.10 Armed attacks:

MQ-1 Predator UAVs armed with Hellfire missiles are increasingly used by the U.S. as platforms for hitting ground targets. The advantage of using an unmanned vehicle rather than a manned aircraft in such cases is to avoid a diplomatic embarrassment should the aircraft be shot down and the pilots captured, since the bombings take place in countries deemed friendly and without the official permission of those countries. A Predator based in a neighboring Arab country was used to kill suspected al-Qaeda terrorists in Yemen on November 3, 2002. This marked the first use of an armed Predator as an attack aircraft outside of a theatre of war such as Afghanistan.

In 2012, the USAF trained more UAV pilots than ordinary jet fighter pilots for the first time.

One issue with using armed drones to attack human targets is the size of the bombs being used and the relative lack of discrimination of the 100 lb (45 kg) Hellfire, which was designed to eliminate tanks and attack bunkers. Smaller weapons such as the Raytheon Griffin and Small Tactical Munition are being developed as a less indiscriminate alternative, and development is underway on the still smaller US Navy-developed Spike missile. The payload-limited Predator A can also be armed with six Griffin missiles, as opposed to only two of the much-heavier Hellfires.

UAVs will likely play an increased role in search and rescue in the United States. This was demonstrated by the use of UAVs during the 2008 hurricanes that struck Louisiana and Texas. Micro UAVs, such as the Aeryon Scout, have been used to perform Search and Rescue activities on a smaller scale, such as the search for missing persons. For example, Predators, operating between 18,000–29,000 feet above sea level, performed search and rescue and damage assessment. Payloads carried were an optical sensor, which is a daytime and infrared camera in particular, and a synthetic aperture radar (SAR). The Predator's SAR is a sophisticated all-weather sensor capable of providing photographic-like images through clouds, rain or fog, and in daytime or nighttime conditions, all in real-time. A concept of coherent change detection in SAR images allows for exceptional search and rescue ability: photos taken before and after the storm hits are compared, and a computer highlights areas of damage.

14.11 Conservation:

In June 2012, WWF announced it will begin using UAVs in Nepal to aid conservation efforts following a successful trial of two aircraft in Chitwan National Park, with ambitions to expand to other countries, such as Tanzania and Malaysia. The global wildlife organization plans to train ten personnel to use the UAVs, with operational use beginning in the fall. In August 2012, UAVs were used by members of the Sea Shepherd Conservation Society in Namibia to document the annual seal cull. In March 2013, the Times published a controversial story that UAV conservation non-profit ShadowView, founded by former members of Sea Shepherd Conservation Society, had been working for several months with anti-hunting charity The League Against Cruel Sports to expose illegal fox hunting in the UK, hunt supporters have argued that using UAVs to film hunting is an invasion of privacy.

14.12 Forest fire detection:

Another application of civil UAVs is the prevention and early detection of forest fires. The chief exponent of this type is the FT-ALTEA, developed by Flightech Systems. The possibility of constant flight, both day and night, makes the methods used until now (helicopters, watchtowers, etc.) become obsolete. Its payload consists of numerous cameras (HD, thermal, hyperspectral, etc.) and multiple sensors that provide real-time emergency services, including information about the location of the outbreak of fire as well as many factors (wind speed, temperature, humidity, etc.) that are helpful for fire crews to conduct fire suppression.

14.13 Archaeology:

In Peru archaeologists use drones to speed up survey work and protect sites from squatters, builders and miners. Small drones helped researchers produce three-dimensional models of Peruvian sites instead of the usual flat maps—and in days and weeks instead of months and years.

Drones have replaced expensive and clumsy small planes, kites and helium balloons. Drones costing as little as£650 have proven useful. In 2013 drones have flown over at least six Peruvian archaeological sites, including the colonial Andean town Machu Llacta 4,000 metres (13,000 ft) above sea level. The drones continue to have altitude problems in the Andes, leading to plans to make a drone blimp, employing open source software.

Jeffrey Quilter, an archaeologist with Harvard University said, "You can go up three metres and photograph a room, 300 metres and photograph a site, or you can go up 3,000 metres and photograph the entire valley."

14.14 Future potential:

In the future, UAVs may be able to perform a variety of unique tasks apart from what they are capable of today. Engineers are currently working to produce remotely piloted UAVs that are capable of air to air combat, aerial refueling, combat search and rescue with facial recognition, and resupply to agents on the ground.

Autonomy technology that is important to UAV development falls under the following categories:

- Sensor fusion: Combining information from different sensors for use on board the vehicle
- Communications: Handling communication and coordination between multiple agents in the presence of incomplete and imperfect information
- Path planning: Determining an optimal path for vehicle to follow while meeting certain objectives and mission constraints, such as obstacles or fuel requirements
- Trajectory Generation (sometimes called Motion planning): Determining an optimal control manoeuvre to take in order to follow a given path or to go from one location to another
- Trajectory Regulation: The specific control strategies required to constrain a vehicle within some tolerance to a trajectory

- Task Allocation and Scheduling: Determining the optimal distribution of tasks amongst a group of agents within time and equipment constraints
- Cooperative Tactics: Formulating an optimal sequence and spatial distribution of activities between agents in order to maximize the chance of success in any given mission scenario

To some extent, the ultimate goal in the development of autonomy technology is to replace the human pilot. It remains to be seen whether future developments of autonomy technology, the perception of the technology, and, most importantly, the political climate surrounding the use of such technology will limit the development and utility of autonomy for UAV applications. Also as a result of this, synthetic vision for piloting has not caught on in the UAV arena as it did with manned aircraft. NASA utilized synthetic vision for test pilots on the HiMAT program in the early 1980s, but the advent of more autonomous UAV autopilots greatly reduced the need for this technology.

Solar-electric UAVs hold potential for unlimited flight, a concept originally championed by the AstroFlight Sunrise in 1974 and the much later Aerovironment Helios Prototype, which was destroyed in a 2003 crash.

14.15 Endurance:

Because UAVs are not burdened with the physiological limitations of human pilots, they can be designed for maximized on-station times. The maximum flight duration of unmanned aerial vehicles varies widely. Internal combustion engine aircraft endurance depends strongly on the percentage of fuel burned as a fraction of total weight (the Breguet endurance equation) and so is largely independent of aircraft size.

One of the uses for a high endurance UAV would be to "stare" at the battlefield for a long period of time to produce a record of events that could then be played backwards to track where improvised explosive devices (IEDs) came.

15. CONCLUSION

1. An unmanned vehicle like “Quadrotor” has many applications.
2. It can be used to decrease man hours and man power, as in it can be used by guards of our own institute campus to survey the campus by the use of camera installed on it.
3. Various other telemetric sensors can also be installed on it like sensors to detect toxic gases or various pressure and temperature sensors, and it can be used where the condition is hazardous for men.
4. It can also be used for carrying pay loads from one place to another which can decrease use of man power and in turn can result into economic profit.
5. The eye i.e. the camera installed on the “Quadrotor” can be used for ethical spying and patrol.
6. There can be innumerable uses of a UAV like “Quadrotor” in coming future mostly in the field of military. The Russian military force has a “Quadrotor” in which a machine gun is installed and is so designed that it can handle recoil from gun firing also.

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