International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-2, Issue-12, December 2014

Design and Modeling of a Verticopter and Control using Graphical User Interface (GUI).

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Abstract— **With the advancement of technology in each and every sector, aviation has always played a vital role in innovations and new designs. One of the types of aircraft initially designed for military purpose only is VTOL i.e. Vertical Take-off and Landing. After taking off vertically while converting to forward motion, VTOL aircraft may face accident because of not generating sufficient lift. At the time of conventional landing, propellers having large area may hit ground causing damage to propellers and also aircraft may crash. To overcome these problems, a designed concept came in existence that is as Verticopter.**

Verticopter is a tilt rotor aircraft, having contra rotating motors with the propellers mounted on co-axial shaft, which takes off and lands vertically like chopper and flies like an airplane. A back to back mounting of motors having single axis creates thrust vectoring mechanism. PIC-18 microcontroller is used as a programmer to control flight motion by controlling motor speed and servo motion. All these control are operated through Graphical User Interface (GUI) by laptop. MPLAB software is used for programming microcontroller and MATLAB software for GUI. Radio frequency modules (receiver-transmitter) are used for transmitting signal.

Index Terms— **VTOL, Co-axial motors, Vertical take-off and landing, Tilt rotor aircraft, Thrust vectoring mechanism, GUI.**

I. INTRODUCTION

Aerodynamics is related to the study of forces and motion of objects through the air. With the development of countries and the race to be best in every sector made army, navy and air-force important sector of development. As a fastest and superior mode of transport, aircraft has been given a prime importance. As for every aircraft it is not possible to have a proper runway for take-off and landing at each and every condition leads to the development in vertical take-off and landing (VTOL) concept.

Vertical Take-Off and Landing (VTOL) aircrafts are able to take-off with the agility of a helicopter and it can fly like an aircraft. [2] These aircrafts have ability to land as conventional airplane. By definition, these aircrafts must be able to take-off vertically and transition into conventional flight and be able to return to hover mode for landing.

Manuscript received December 12, 2014.

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For taking-off and landing, the two wingtip of an aircraft mounted engine arms are tilted upward, so that the rotors function like a rotor blades as there in helicopter. For forward flight, the engine arm having rotor blade are rotated 90 degrees forward, so that the rotors blades function like an airplane's propellers. For a VTOL aircraft, the engines and wings are located relative to each other's position such that the engine outlet nozzles which pivot downwardly to provide lift and are area covered by the wings support while lifting creating resistance.[7] Sometimes, the wings may be supported with lifting fans for supplement lift and provide pitch and roll control.

A microcontroller and GUI controlled planes ranges from small to large models made up from a variety of materials such as balsa wood, carbon fiber and high density thermocol (HDT). These planes don't need engines for flying; they are mostly equipped with electric motors or gas engines to rotate propellers so as to reach desired altitude. The motion of motor is controlled by microcontroller programming. An aircraft consist of one, two or four engines. The engines used in an aircraft are basically gas turbine engines which work on varying area flow concept. An aircraft which take-off and land vertically mainly has various types of engines such as turboprop, turbojet, and turbofan. In earlier phase of VTOL, planes having IC engines were used such as X-41. The turboprop engine is used in case of V-22 Osprey and turbojet in case of F-35.[5]

In commercial aircrafts these engines are generally located below the wings so that proper airflow can be maintained. In VTOL the engines with propellers are located either centrally or at the tip of a wing.

The use of flight simulation by generating a dynamic model of an aircraft has become an important need of all aviation industries. It is a method through which the in-flight reactions of an aircraft depending on various factors such as different parametric dimensions, environmental conditions and control inputs can be visualized through the developed outputs in the form of graphs. The calculated values are even in the form of real environment. The reason, it has become an integral need of any research and development team is that flight simulation has made a major contribution to improve aviation safety and provides stability while flying.

II. THEORY OF FLIGHT CONTROL

In flight, the aircraft rotates about its center of gravity, but the direction of the forces due to its weight always remains towards the center of the earth.

Lift is the force generated in order to overcome the weight which acted downward, and makes the aircraft fly. This force is obtained by the motion of the aircraft propellers through the air. Drag is the Aerodynamic force that resists the aircraft's motion through the air. Drag is generated by each and every part of the aircraft. Thrust is the force generated i to overcome the drag which helps the aircraft fly in forward direction.[3]

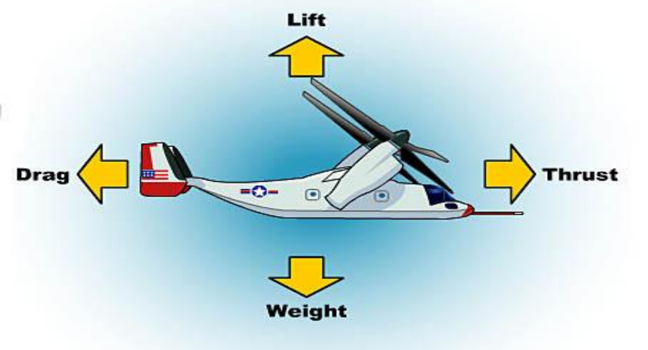

Fig. 1 Forces in Flight

During flight there are total six degrees of freedom. Vertical, longitudinal and lateral are three basic degrees of freedom where in addition to that pitching rolling and yawing motion helps to maintain maneuverability.

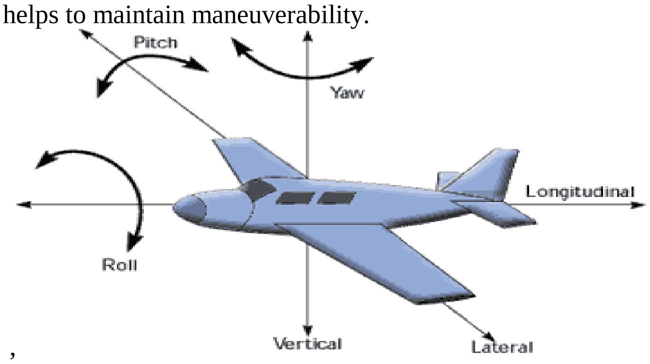

Fig. 2 Degrees of Freedom

III. Methodology

In VTOL after taking off vertically while converting to forward motion, aircraft may face accident because of not generating sufficient lift. At the time of conventional landing, propellers having large area may hit ground causing damage to propellers and also aircraft may crash. To overcome these problems, a designed concept came in existence that is as Verticopter.

Verticopter is a tilt rotor aircraft, having contra rotating motors with the propellers mounted on co-axial shaft, which takes off and lands vertically like chopper and flies like an airplane. A back to back mounting of motors having single axis creates thrust vectoring mechanism**.** Propellers are installed on two contra rotating motors to have puller pusher action. This pusher puller mechanism generates maximum lift while it takes off. Two servo motors have to be used to rotate this thrust vectoring mechanism from vertical position to forward position and vice versa. Thrust vectoring mechanism is set to any desired position to have maximum lift.

PIC-18 microcontroller is used as a programmer to control flight motion by controlling motor speed and servo motion. All these control are operated through Graphical User Interface (GUI) by laptop. MPLAB software is used for programming microcontroller and MATLAB software for GUI. The advantages of using Graphical User Interface for flight simulation are that the user can change the initial conditions of all motion variables and control inputs and the corresponding response of the aircraft can be analyzed. Radio frequency modules (receiver-transmitter) are used for transmitting signal.

IV. Block Diagram and Development of Model

The basic block diagram of a model with the entire component is:

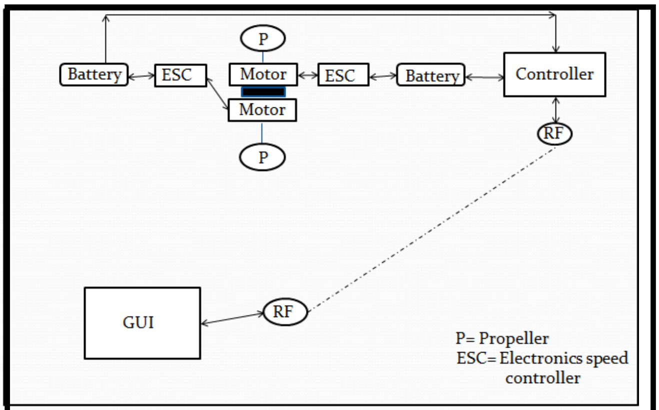

Fig. 3 Block Diagram

The basic component selection and their weight calculation helps to calculate the thrust require during vertical take-off and during hovering.

Component Selection:

High Density Thermocol, Batteries, Brushless motors, Electronic speed controller, Servo motors, Propellers, PIC 18 microcontroller Radio frequency module (receiver and transmitter).

Each component selection depends on specifications of other components. For proper thrust and lift production synchronization of all components is important.

Thrust Calculations:

As per the theory during vertical take-off, the thrust required for take-off should be 1.25 times that of the weight of the body. This required thrust depends on motors power and battery voltage supply.

S. No	Component	Approximate weight (kg)
1	Body (HDT)	0.5
2	Batteries	0.18*2 = 0.36
3	motors	0.15*2 = 0.3
4	Electronic speed controller	0.035*2 = 0.07
5	Servo motors	0.05 *2 = 0.1
6	Propellers	0.015*2 = 0.03
7	Skidders	0.1
8	PIC18 Microcontroller	0.1
9	RF Module	0.01
	Total	**1.57**

Table 1: Weight calculation

Calculations:

The thrust required during vertical take-off is

Thrust = 1.25 × weight of a model

= 1.25 × 1.57
= 1.9625 kg.
The thrust required during hovering is
Thrust = weight of a model
= 1.57 kg

Development of model:

The high density thermocol sheets with dimensions 20mm are used for making of base portion of model Araldite is used as glue to give strength to model. Wingspan of model is 90 cm and nose to tail distance is 70 cm. Elliptical shape of minor diameter 31 cm and major diameter of 29 cm is cut through center of base for mounting of cowling. Cowling is a protective covering for propellers and it is also for the safety of user. It is usually made up of metal or plastic as weight is important factor. As plastic is light weight material so the preference is given to plastic for construction of cowling. Cowling of airfoil shape is cut having dimensions 10cm and 5cm at leading edge and trailing edge respectively so as to obtain aero-foil shape
The cowling is drilled diametrically and two bearings of inner diameter 5mm are fit into it. Carbon fiber rod having outer diameter 5mm is inserted into two bearings.

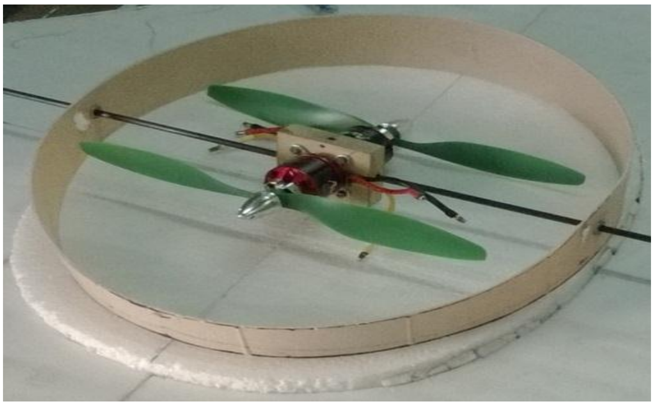

Fig 4:- Cowling with thrust vectoring mechanism

These bearings are used to sustain load and to prevent bending of carbon fiber rod. Bearings also allow the mounting to rotate without any vibration. Diameter of cowling is decreasing from top to bottom so it will act as air duct. It allows air to flow downward at high pressure due to duct effect.
Balsa wood is cut as per dimensions required for mounting motors. Through a block of 75×70×40 mm a drilled with 5 mm diameter at center is done. Carbon fiber rod of 5mm diameter is fixed in it. Four holes are drilled on upper and bottom face of balsa wood. Motors are mounted on these holes axially on opposite faces. Rotation of upper motor is counter clockwise and lower one is clockwise which creates puller-pusher action of propellers.
A carbon fiber rod is passed through the two bearings fixed in cowling diametrically which sustain the weight and stress of motor assembly. But at the outer side of cowling, rod act as a cantilever beam and it may cause deflection due to its own weight. And this deflection of a carbon fiber rod results in improper working of motor assembly. So, the two wooden blocks with bearings are fitted at both ends. Then the rod is passed through the bearing on both sides. These wooden blocks fixed on a model symmetrically such that it gives stability to rod.
For the rotation of motor assembly orthogonally from vertical to forward and vice versa, rotation of a rod has to be done by servo motor only. Drilling to a 5mm carbon fiber rod is very difficult so a wooden block of 20×20×30 is fitted to carbon rod and its motion is controlled by servo motor arm with the help of aileron horns and clevises and transmission rod. The rotation of servo arm through 90˚ results in rotation of rod orthogonally.

V. PIC 18 MICROCONTROLLER

PIC microcontrollers are belongs to modified Harvard architecture family. The name PIC means ‘Peripheral Interface Controller. The PIC architecture is characterized with separate code and data space, small numbers of fix length instruction. In PIC most instructions are single cycle execution with one delay cycle on branches and skips.

The PIC microcontrollers are available with various on-board peripherals such as UARTs, motor control kernels and serial communication modules. The program memory of PIC varies from 256 words to 64000 words and more.

In verticopter the PIC act as a brain of model giving signal for working of a model. The on-off signal to microcontroller is given through GUI using Radio Frequency receiver-transmitter connected to both laptop and microcontroller.

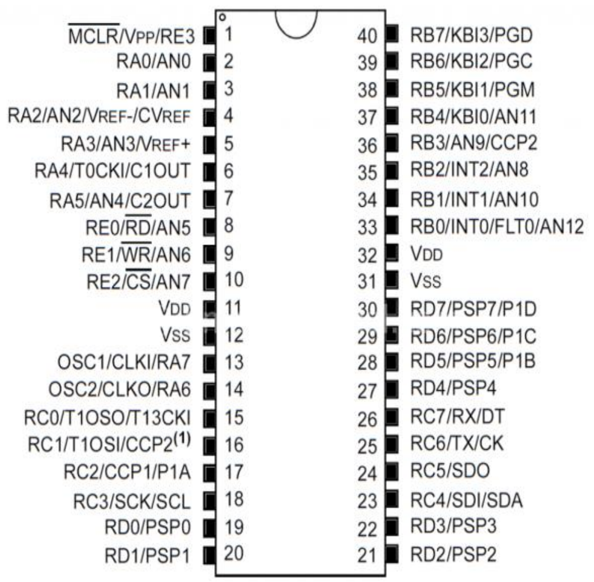

Fig 5:- PIC 18 pin diagram

VI. GRAPHICAL USER INTERFACE

MATLAB i.e. Matrix Laboratory which supports in developing applications with graphical user interface is a multi-paradigm numerical computing environment MATLAB have ‘guide’ development environment.

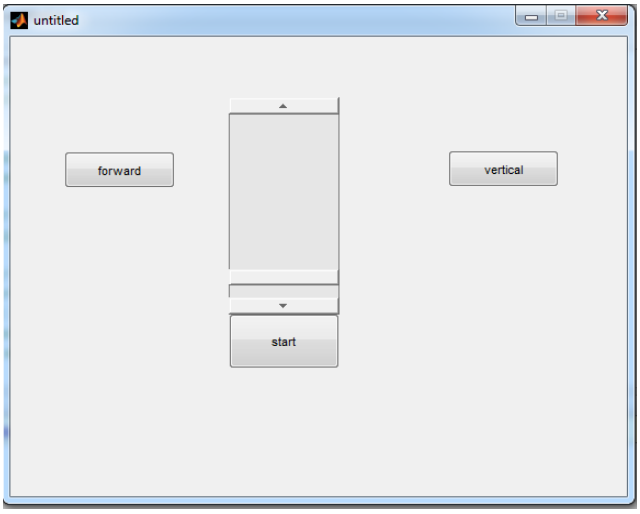

Fig 6:- Graphical User Interface window

GUI's are created using a tool called 'guide' (GUI Development Environment). This function allows the user to create the GUI and modify the layout according to the need of the user. Also the user can edit their properties.

By using the GUI window the signal are send to microcntroller with the help of RF receiver-tramsmitter module.

The motion of verticopter is performed as:

Start: When the 'start' button is pressed the program to start the motor at min RPM of 1200 is loaded into the microcontroller and the BLDC is excited with appropriate pulse.

Throttle: After starting, the speed of the motors is increased is by giving 'throttle', by slider throttle used in GUI

Horizontal- When the 'Horizantal' button is pressed the program that is linked with it is sent to the microcontroller via the RF module. This program instructs the servo to turn by 90 degress in from vertical to horizotal position. In this position the aircraft can manuver in horizontal directioon. By increasing speed of motor in this position the verticopter moves in forward motion.

Vertical: When the 'vertical' button is pressed the program that is linked with it is sent to the microcontroller via the RF module. This program instructs the servo to turn by 90 degress in from horizontal to vertical position. This position is required to gain the altitude for lift of the aircraft. This position is for vertical take-off and landing of the verticopter.

VII. WORKING OF MODEL

Two motors are mounted back to back coaxially, forming counter rotating motors mechanism. These counter rotating motors assembly mounted on rod are connected to batteries having electronic speed controller connected to them for controlling speed. Back to back mounting of motors, form puller-pusher mechanism for propellers. In this mechanism air is pull by upward propeller rotating in clockwise direction and downward propeller pushes air down which is rotating in counter-clockwise direction, creates the lift. After giving signal to microcontroller thorugh GUI, throttle is provided due to which propellers start rotating. After acquiring a certain speed, the thrust is generated due to which an aircraft takes off siganl vertically. To provide throttle the left key is pressed.

During a vertical motion, when an aircraft is reached to a desired altitude, the rod having counter rotating motor assembly mounted on it, is rotated orthogonally forming a forward motion mechanism. Rotation of rod is done by servo motors connected to it. The servo motors are rotate by giving signal to servo motor by pressing left key. An aerodynamic shape of a body helps to move an aircraft in forward direction.

VIII. CONCLUSION

The project design and modeling of a remote controlled motored vertical take-off and landing aircraft with axially mounted counter-rotating motors has more advantages compare to its disadvantages. This vertical take-off and landing aircraft does not need any run way for take-off and landing. Due to its large wing span area it has low speed gliding capability. It is very stable like co-axial helicopter. It is as fast as turbo propelled aircraft. It has very high cruise speed same as turboprop.

It has drawbacks such as it requires large amount of thrust, therefore being an issue to carry heavier loads. Higher trust needing more complex equipment and therefore the cost of the whole process increases substantially.

However in an era which needs faster modes of transport vertical take-off and landing is the future of aviation. In naval ships deck area is very limited so vertical take-off and landing is the solution to this problem which has high speed, long distance covering capacity, high load carrying capacity and stable flight. So it is also useful for army and air force. For cities which are getting densely populated and have no room for big airports, vertical take-off and landing serves as the best substitute. Also lowering the number of control surfaces eases the part of flying along with reduced cost and size of the aircraft.

VIII. FUTURE SCOPE

As verticopter can fly as helicopter as well as airplane so by fixing gas detector sensor it can be used for inspection of piping system. Also for military surveillance it can be used. It can be made as stealth so that it can't be recognized on radar so that can used as spy. Using human body sensor on the aircraft model it can be helpful in finding human body in case of flooded and earthquake affected area.

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