Design and Fabrication of Two Rotors Bicopter

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Abstract—In the field of aerodynamics, use of Unmanned Aerial Vehicle (UAV) has grown rapidly because of their ability to operate in dangerous locations while keeping their human operators at a safe distance. One of the common UAV is bi-copter. Bi-copter is a simple UAV used in defense sector to provide casualty evacuation solutions, medical assistance and surveillance in dangerous locations. Bi-copter has smaller diameter rotors and is simpler in design compared to helicopter.

The work behind this project is inspired by the hover bike concept of Malloy Aeronautics. It has the feature of vertical takeoff and landing using two rotors. The vertical takeoff of the bi-copter is based on Bernoulli’s energy concept. The vertical takeoff is due to the pressure difference on the upper and bottom surface of the propeller which is aero foil in shape. In this project an attempt is made for developing a UAV using two rotors. Initially, parts of the copter are modeled and assembled by using CATIA V5 software and then the parts are analyzed by using Ansys Workbench 13.0 to decide the wall thickness and to validate the designs (Analysis part is not discussed in this paper). Aluminum 5052 is selected for the fabrication of parts of the copter, based on the strength to weight ratio, ease of fabrication, cost and availability. Copter parts are fabricated based on the part drawings by taking aluminum 5052 as a material. Once the fabrication is completed, priority is given to the motors and other control elements. Finally, the components which are essential for the working of bi-copter are installed into the manufactured skeleton.

The objective of this project is to study and fabricate a bi-copter that can be controlled by a wireless communication system. This includes selection of the right material and electronic components. The project also deals with testing the performance of the bi-copter. Bi-copter is controlled by using wireless communication system. The wireless communication system consists of a transmitter that sends signals to the receiver, and then the receiver inputs these signals to the microcontroller. The bi-copter balancing condition is sensed by sensors and gyro. Multi-rotor controller is used to stabilize the bi-copter during flight. Controller takes signals from the gyroscopes (roll, pitch and yaw) and passes these signals to the processor, which in turn process these signals. The processor passes the control signals to the installed Electronic Speed Controllers (ESCs). ESCs regulate the speed of the brushless DC motors to obtain stability of the bi-copter. Flight testing is done to detect the flying and balancing problems. Problems occurred during flight testing trials are rectified with slight modifications.

Keywords—UAVs, Helicopter, bi-copter, Part modeling, Manufacturing, Control systems, Flight testing.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAV) are unmanned flying aircrafts. They are different from the commercial aircrafts and jets in a way that it does not have an on board pilot. Generally the pilot in a UAV controls the motion from the ground through a remote. Advanced development in the field has resulted in autonomous UAVs and the need of a pilot is eliminated. Such UAVs have an on-board controller that takes care of the stability and the trajectory motion of the UAV. Bi-copter is a simple UAV with two rotors. It requires only 20% of the required deck area compared to helicopter. It is
quiet and safe around people due to the presence of ducted rotors. The bi-copter can take off and land vertically within limited space. It can be used in dangerous locations keeping the human operators safe. The bi-copter operation range is limited based on the transmitter and receiver capacities. The bi-copter can operate efficiently in dry condition. It has less lifting power and is less stable compared to all other multi-copters. The bi-copter requires a very robust electronic autopilot to maintain control of the vehicle. Research and development of unmanned aerial vehicle (UAV) and micro aerial vehicle (MAV) are getting high encouragement nowadays, since the application of UAV and MAV can apply to variety of area such as rescue mission, military, film making, agriculture and others. To encourage missions in dangerous situations, flying stages that can take of vertically are of importance. A stage that satisfies these necessities is a UAV (Unmanned Aerial Vehicle) as a multi copter joined with a great control framework.

In a world where vertical take-off and landing missions are critical, it appears that helicopters have become the primary vehicles of choice. Throughout the history of such vehicles, there has been a number of alternative solutions to the vertical flight problem. One such alternative is known as the ducted fan. Ducted fans and ducted rotors have been integrated into a wide range of aerospace vehicles, including manned and unmanned systems. Ducted fans offer many potential advantages, the most important of which is an ability to operate safely in confined spaces. There is also the potential for lower environmental noise and increased safety in shipboard operations (due to the shrouded blades). However, ducted lift fans in edgewise forward flight are extremely complicated devices and are not well understood. Technological improvements in lithium polymer batteries, which have a higher specific energy density than nickel metal hydride or sealed lead acid batteries with more favorable packaging capabilities, allow us the possibility of improved flight times and performance. Improvements in the embedded systems to govern the vehicles behavior, such as the open source Arduino chips, and Raspberry Pi computer-on-a-chip, are affordable platform to program autonomous piloting systems for such vehicles.

This Project is focused on developing a remotely operated bi-copter system. The bi-copter is controlled through graphical user interface (GUI). Communication between GUI and bi-copter is done by using wireless communication system. The bi-copter balancing condition is sensed by IMU sensors. All signals from sensors are processed by kk2.1 microcontroller board. Output from kk2.1 microcontroller board is used to control bi-copter propellers. The experiment shows that bi-copter can hover while maintaining its balance and stability. Bi-copter can accept load disturbance up to 250g during it hover condition. Maximum operated time of bi-copter is six minutes using 2200mAh Lipo battery and operate time can be increase by using high capacity battery. The bi-copter is fabricated using aluminum sheet. All the electronic parts are assembled on the bi-copter body. The brushless motors are tested and then the bi-copter is tested for its various motions. The stability of bi-copter is checked during flight testing.

1.1 Working of Bi-copter

The bi-copter works on the principle of Tandem Rotors Helicopter. Tandem rotor helicopters have two large horizontal rotor assemblies mounted one in front of the other. Tandem rotor helicopters, however, use counter-rotating rotors, with each cancelling out the other's torque. Therefore all of the power from the engines can be used for lift (force), whereas a single rotor helicopter uses some of the engine power to counter the torque. The two rotors are linked by a transmission that ensures the rotors are synchronized and do not hit each other, even during an engine failure [3]. Tandem rotor designs achieve yaw by applying opposite left and right cyclic to each rotor, effectively pulling both ends of the helicopter in opposite directions. To achieve pitch, opposite collective is applied to each rotor; decreasing the lift produced at one end, while increasing lift at the opposite end, effectively tilting the helicopter forward or back. Advantages of the tandem-
rotor system are a larger center of gravity range and good longitudinal stability. Disadvantages of the tandem-rotor system are a complex transmission, and the need for two large rotors. Tandem rotors force distribution is shown in figure 1.

The bi-copter is controlled through Graphical User Interface (GUI). Communication between GUI and bi-copter is done by using wireless communication system. The bi-copter balancing condition is sensed by sensors and gyros. Multi-Rotor controller is used to stabilize the bi-copter during flight. Controller takes signals from the on-board gyroscopes (roll, pitch and yaw). It passes these signals to the processor, which in turn processes these signals. The processor passes the control signals to the installed Electronic Speed Controllers (ESCs). ESCs regulate the speed of the brushless DC motors to obtain stability of the bi-copter.

![Image of tandem rotors force distribution]

**Figure 1. Tandem rotors force distribution**

## II. OBJECTIVES

The main objectives of this project are:

a) To design Bi-copter that can be controlled using wireless computer.

b) Material selection and Static analysis of the bi-copter parts to decide the strength and wall thickness

c) Manufacturing of bi-copter based on part drawings.

d) To test the performance of designed bi-copter for validating the design.

## III. METHODOLOGY

Figure 2 shows the flow chart that represents the stages in which project is completed. Fabrication of bi-copter is divided into two stages, they are; Stage 1: Part design and Stage 2: Full interface.

![Diagram of flow chart]

**Figure 2. Flow Chart**
IV. MODELLING OF BICOPTER COMPONENTS

Components of bi-copter are modeled in CATIA V5 software, taking Aluminum as material keeping weight to power ratio in mind. Modeling of each component is discussed in brief in following sections.

4.1 Duct
Duct encloses the motor and propeller. The duct is inclined at the top to allow greater air flow. This results in higher thrust generation. Aluminum is considered as a material for duct. The diameter of the central portion of the duct is chosen to suit the 10” propeller size. The diameter of this part is 260 mm and it is 25 mm in height. The top portion is 20 mm in height and is inclined at 130 degree from the horizontal to allow greater air flow. The bottom portion is inclined at 110 degree from the horizontal and is 15 mm in height. The duct reduces the noise produced by the propellers. Due to the presence of duct, the bi-copter is safe around humans. Following figures show 2D drawing and 3D model of duct.

![Figure 3.1. 2D drawing of Duct](image1)
![Figure 3.2. 3D model of Duct](image2)

4.2 Connecting plate
The connecting plate connects the two ducts of a bi-copter. The curvature of connecting plate matches with that of the duct. A central hole is provided for wire passage across the sides of the plate. Dimension of the plate is 150mm X 125mm and aluminum is considered as a material. The connecting plate holds the two ducts and carries the microcontroller, battery and other electronics. Two ribs are provided at the bottom of the connecting plate to provide additional strength. 2D drawing and 3D model are shown in figures 4.1 and 4.2.

![Figure 4.1. Connecting plate drawing](image3)
![Figure 4.2. Connecting plate model](image4)

4.3 Motor housing plate
The motor housing plate is designed in accordance with the motor rotational speed. The length of the plate matches the inner diameter of the duct. Two such plates are placed at the central portion of the duct. 32mm hole is provided at the center of the housing plate to fix the motor. Housing plate has three arms of length 129.5 mm from the center. These are welded to the central portion of the duct.
The weight of the motor is distributed equally along the three arms. Small plates of size 25 mm X 10 mm are placed at equal distance between the two motor housing plates to increase the strength of the structure. Figures 5.1 and 5.2 depict 2D drawing and 3D model of housing plate.

4.4 Bi-copter assembly
The bi-copter assembly consists of two ducts, four motor housing plates, two ribs and a connecting plate. Duct encloses two motor housing plates which are separated by 25 mm. These are welded to the duct. A number of small strips are welded between the plates. Two such plates are prepared. The two ducts are united with the connecting plate. Two ribs are provided below the connecting plate to enhance the strength of the structure. Two long strips connecting the two ducts are provided on the sides to obtain good hovering stability.

Modeling and assembly of bi-copter parts is done in Catia V5 software. The material of the bicopter is set to Aluminum for better weight to power and strength ratio. The weight of the structure is found to be 400 grams. Ideal ducted system has 30% power savings compared to the open rotor system to generate the same amount of thrust. The design is quite simple. The limitation of this structure is that it cannot withstand heavy loads. It is designed with respect to the sizes and weights of the electronic components to be used.

V. CALCULATION OF FORCE ACTING ON MOTORS
Manual calculations are done to validate the design. Details of the calculations are briefly explained in this section.

5.1 Force
According to Newton's law of momentum, Force, F=ma
Where, m = mass of the body, a = acceleration by which air is pushed down
Considering our model,
Force produced by the motors can be calculated by law of momentum. From the law of momentum, $F=ma$ where $m$, includes the whole model mass including the mass of the motors. i.e. $m \approx 1.4$ kg. We are using two motors of same kind in front and aft section. The total weight or the force is distributed equally on both of the motors. Each motor has a mass distribution of 0.7 kgs on it. Motor which we are using is 1120 kv motor that can have a maximum thrust of 1.2 kgs. Considering 1 kg as the maximum thrust that can be produced by the motors, 

Force that motor can lift is, $F=1 \times 9.81 = 9.81$ N

We have $F=ma$. 

Mass = 0.7 kgs

$1 \times 9.81 = 0.7 \times a$

From which we can calculate the acceleration $a=14.01 m/s^2$ 

Considering the time required for the motor to produce 1 kg of force, as the current voltage is applied using the transmitter as 1 sec. 

$t=1$ sec.

Velocity, $v= a/t = 14.01/1= 14$ m/s (This velocity is used as the velocity input for the static thrust calculations). 

**Static thrust calculations:**

For the UAVs the thrust is calculated based upon the momentum theory. This theory deals with the air density, velocity and the arrangement of the model.

**Thrust**

Thrust is simply the uplift force produced by the motor. To calculate the thrust produced by the DC brush less motor, 

We have,

$T = \left[ \pi D^2 \rho P^2 / 2 \right]^{1/3}$

Where, $T$=thrust in Kgs

$D$= diameter of the propeller in m = 0.0254 m

$\rho$= density of air = 1.225 kg/m$^3$

$P$= power of the motor = 27.5 KW

We obtain

$T=9.6$ N

Thrust obtained is approximately same as calculated through newton's law. From the above calculations, we can say that the thrust produced by the two rotors is quite sufficient enough to lift the model. Hence we can proceed with the motors for our experimentations.

**VI ELECTRONIC COMPONENTS**

**6.1 KK2.1.5 Multi rotor control board**

This control board is designed for multi-copter. The LCD screen and built-in software makes installation and set-up easier. The multi rotor controller stabilizes the flight. To do this, it takes signals from the gyroscopes and passes these signals to the Atmega324PA processor, which in-turn processes signals according to the selected firmware and passes the control signals to the Electronic Speed Controllers (ESCs). The combination of control signals instructs the ESCs to make fine adjustments to the motors rotational speeds which in-turn stabilizes the craft. The Hobby King KK2.1 Multi-Rotor control board also uses signals from the radio system via receiver (Rx) and passes these signals together with stabilization signals to the Atmega324PA IC via the aileron; elevator; throttle and rudder user demand inputs. Once processed, this information is sent to the ESCs which in turn adjust the rotational speed of each motor to control flight orientation (up, down, backwards, forwards, left, right, yaw). KK2.1.5 multi rotor control board is shown in figure 7.
6.2 Electronic speed controller
An electronic speed control or ESC is an electronic circuit with the purpose to vary an electric motor's speed, rotor direction and also to act as a dynamic brake. ESCs are often used on electrically powered radio controlled model. Brushless ESC systems basically drive tri-phase brushless motors by sending sequence of signals for rotation. Brushless motors, otherwise called out runners or in runners, have become very popular with radio controlled airplane because of their efficiency, power, longevity and light weight in comparison to traditional brushed motors. Most modern ESCs incorporate a battery eliminator circuit to regulate voltage for the receiver, removing the need for receiver batteries. ESC is shown in figure 8.

6.3 Brushless DC motors
Brushless DC electric motor is also known as electronically commutated motors or synchronous motors, which are powered by a DC electric source via an integrated inverter/switching power supply. Brushless DC motor is shown in figure 9.

6.4 Lithium polymer battery
Lithium polymer batteries are rechargeable batteries. Li-Po batteries are usually composed of several identical secondary cells in parallel to increase the discharge current capability, and are often available in series "packs" to increase the total available voltage. Li-poly batteries are also gaining favor in the world of radio-controlled aircraft, radio-controlled cars and large scale model trains, where the advantages of both lower weight and greatly increased run times and power delivery can be sufficient justification for the price. Li-po battery is shown in figure 10.

6.5 RC transmitter and receiver
An RC Module (Radio Frequency Module) is usually a small electronic circuit used to transmit and/or receive radio signals on one of a number of carrier frequencies. Figure 11 shows RC transmitter and receiver used in bi-copter.
6.6 Propeller
Propeller is also the main part of the quadcopter for flying. There are two types of propellers used CW and CCW. CCW propellers are also called as normal propeller and they are mounted to the motor which is moving in counter clock wise direction. CW propellers are also called as pusher propellers and they are mounted to the motor which is moving in the clock wise direction. Using gyroscopes we can measure the orientation of prototype in X, Y and Z directions.

VII. RESULTS AND DISCUSSION
Bi-copter is fabricated using aluminum commercial grade 5052 sheet. Aluminum is light in weight, has a higher power to weight ratio and good fabrication properties. These properties of aluminum made it possible for laser cutting, rolling of the strips, and tig welding. Welding of 0.8mm thick aluminum parts is quite difficult. Hence, the parts are welded at certain points. As the connecting plate is to bear much weight, two ribs are provided to prevent it from bending. The model is designed in CatiaV5. The bi-copter frame weighs around 400 grams. The model is analyzed for stress and strain in Ansys Workbench 13. The motor and propeller combination is selected to get the required thrust. The net weight of the bi-copter is around 1 kg. The motors are selected to give a thrust greater than 1 Kg. The bi-copter is balanced after placing all the electronic components on the bi-copter frame. If not balanced the bi-copter may not move in the right direction and it becomes very difficult to stabilize the flight. The battery is placed at the centre to distribute weight equally on both the sides. Then the bi-copter is tested for its vertical takeoff, forward and backward movements. As the throttle is increased in the transmitter the bicopter lifts when the thrust equals its weight. With further increase in the throttle, the bi-copter fly’s high. The microcontroller has in-built sensors that sense any deviation in the flight. The error is input to the processor which processes it and sends control signals to the speed controllers to stabilize the flight. The bi-copter is tested multiple times by changing the roll axis trim and pitch axis trim values in the self-level settings for ideal flight. The bi-copter moves in the forward and backward directions by increasing the speed of the respective motors.

VIII. TESTING OF BICOPTER
Electronic components are assembled on the bi-copter frame then the motors are placed in the motor housing. Motors are connected to electronic speed controllers which in turn are connected to the microcontroller. These electronic speed controllers are placed on the vertical strips. Power is supplied to the circuit through a Li-polymer 3S (11.1 voltage) battery (Battery is placed at the center below the connecting plate). Receiver is connected to the microcontroller with three pin wires.
Initially, the bi-copter is placed on a level surface. Microcontroller is positioned at the center. Microcontroller is turned on by connecting the battery and the voltage distribution board. The gyro and sensor tests are done by using the push buttons on the controller board. Transmitter stick calibration is performed. Bi-copter configuration is activated in the microcontroller. The electronic speed controllers are calibrated so that the upper limit of transmitter stick movement gives the full thrust. The calibration of Electronic Speed Controller (ESC) is performed by initially holding the first and last push button on the microcontroller when the battery is not connected. Now, the transmitter throttle stick is kept at its maximum and the battery is connected. The microcontroller turns on and we hear a starting music this is followed by beep sound. Push the transmitter throttle stick to the minimum after hearing two beeps. Wait for the third beep that indicates electronic speed controller calibration is completed. Then release the first and last push button on the microcontroller this completes the ESC calibration. Before performing the actual stability test, we check for the speed regulation by the microcontroller. Start the bi-copter and increase the throttle to 50%. Now hold the bi-copter with your hands at the side and tilt the bi-copter so that one of the ducts is lowered. The speed of the motor that is lowered has to increase. If this is not the case, then either the propellers or the ESCs are wrongly connected to the motors. This condition has to be checked before hovering the bi-copter.

**Trial 1**
Self-level is on and the transmitter input is provided to arm the bi-copter. Throttle is increased to 70%. But the bi-copter remains in contact with the ground. This shows trial one is failed. The reason being the two motors are not connected to the right ESC’s.

**Trial 2**
ESC connection is corrected. Bi-copter is activated and the throttle is increased to around 65%. At this stage the bi-copter lifts off the ground. With further increase in the throttle, the bi-copter flips and falls upside down.

**Trial 3**
The failure in the previous trial is due to the roll axis settings defined incorrectly. The roll axis is adjusted and the bi-copter is tested. As throttle is increased it rises up to two meters. With increase in one motor speed, the bi-copter moves in that direction. The bi-copter stays in the air for about eight minutes before the 11.1 voltage battery drains.

**IX. CONCLUSION**
The main focus of our project was to study, fabricate and test the most unique and unstable model of UAVs, which is a bi-copter. The major problem was to stabilize the bi-copter. The stability is in terms of making it hover and achieving control over it. The two motors with propellers in front and back section were the main thrust power suppliers. Pitching, rolling and yawing were the difficulties to attain with only two motors. We encountered very harsh failures of our model which includes...
damage to the frame and other electronic components during the bi-copter flight tests. Bi-copter was flipping over and used to crash during landing. Later we had conducted many tests on the basis of trial and error methods, by approaching some changes to the microcontroller settings every time we test it. Through a series of iterative processes and experimentation, the UAV was able to achieve its objectives that were set out in the beginning. It was able to fly through confined indoor spaces, was able to survive colliding with obstacles, and was able to take off vertically, land and yaw along the ground and take-off again. Bi-copter was finally stabilized after many tests. Based on the quoted specifications of the components, the bi-copter was able to move three meters in vertical direction and stay in air for about eight minutes also succeeded in moving in the forward and backward directions. The wireless communication system helped in controlling the bi-copter flight within twenty meter radius from the receiver. From the above study, fabrication and testing of a bi-copter, it is possible to produce a small scale UAV with two rotors that could be used for both military and commercial use.

REFERENCES