Development of a Fixed Wing Unmanned Aerial Vehicle Using NACA 4414 Airfoil

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Acknowledgement

First of all we would like to thank our Almighty Creator for the successful completion of our first team project as undergraduate students of Shahjalal University of Science and Technology. This project contains contribution of so many good people. Without their helps, their inspiration and their guidance this project may not have seen light. We take this opportunity to express our profound gratitude and deep regards to our respected teacher:

Nuruzzaman Sakib
Lecturer,
Department of Mechanical Engineering,
Shahjalal University of Science & Technology.

The blessings, help and guidance given by him time to time shall carry us a long way in the journey of our life on which we are about to embark.

We express our sincere gratitude to the Mechanical Engineering Department for providing us such an opportunity for implementing the ideas in our mind in such a beautiful way.

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Abstract

Unmanned Aerial Vehicles (UAVs) or Drones have become a vital component of the defense aircraft industry internationally in recent years. It is largely used for monitoring, surveillance, investigation, data relay, and data collection or to enter the area which is not safe for human i.e. flood affected or virus affected area. The Fixed wing UAVs are preferred over common rotor wing type UAVs in defense purposes due to their high speed response and versatility. This project represents unique design of such a UAV, in which NACA 4414 airfoil is used as the wing. This glider type UAV has been designed to serve two vital surveillance applications: area monitoring using a HD camera and payload dropping. In case of material selection to implement the project, low cost local materials have been preferred. The UAV is controlled using radio controller. It is known that, wing profiles or airfoils have a large influence on the lift and efficiency of UAV wing structures and therefore, a CFD study has been done on ANSYS 15.0 Fluent module to investigate the aerodynamics characteristics of NACA 4414 airfoil as a wing using Spallart-Allmaras model. The airfoil has been numerically investigated with different angle of attacks and the most preferable and efficient angle of attack has been used in actual structural design of the Unmanned Aerial Vehicle. This holistic approach has led to an efficient and economical model of fixed wing Unmanned Aerial Vehicle. The details of the developed fixed wing Unmanned Aerial Vehicle (UAV) will be presented in the project report.

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Chapter 1

Introduction

This course of Level-3, Term-2 of Mechanical Engineering Department of Shahjalal University of Science and Technology gave us a chance to practice all the knowledge and skills which we already have gained along the academic session in solving practical life problems through a project in order to be an efficient and a good engineer.

1.1Background & Motivation

There is a notable revolution which is intended to be an ingenious development in the area of communication and transportation: the drones [1]. An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot aboard. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by onboard computers [2].
From history, it is found that UAVs were used in those cases where job was too “risky, unhygienic and dirty”. Target attacks using UAVs started in World War I and in World War II, when advance guided UAVs were used to drop bombs [3]. While they originated mostly in military applications, their use is rapidly expanding to commercial, scientific, recreational, agricultural, and other applications, such as policing, peace keeping and surveillance, product deliveries, aerial photography, agriculture, smuggling and drone racing [4].
Bangladesh every year purchases a number of UAVs from foreign countries for its defense sector spending a large amount of money. Keeping this in view, we have been inspired to build a defense type fixed wing UAV which can be employed for area monitoring purpose and emergency object dropping using available local materials and technology. These types of UAVs can be easily used in defense works such as surveillance and emergency services. The prime focus in this project has been given to design such a UAV which can serve these types of applications. The main concentration has been given to the design wing, which is basically a NACA 4414 airfoil and flying stability. In addition, the UAV is equipped with an HD quality camera which can be used for area monitoring purpose.

1.2Definition

A UAV is defined as a "powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload" [5]. Therefore, missiles are not considered UAVs because the vehicle itself is a weapon that is not reused, though it is also unmanned and in some cases remotely guided.

Chapter 2

Proposed Methodology

2.1 Approach:

A fixed wing Unmanned Aerial Vehicle has been built which can be controlled using remote control system from the ground and can serve the purpose of payload dropping and area monitoring in HD quality.

2.2 Design:

In this project, the components we used, can be categorized into three main classes: One is external aerodynamics component, second is mechanical component and third is electrical component. The aerodynamics performance of the UAV has been analyzed using the simulation software ANSYS and the outcomes have been later implemented in actual UAV design. The mechanical components which make the body of our product and actually controls the UAV itself. And other is the electrical components which make the circuit to run the UAV. A complete overview of the completed project is provide below:

Fig.2.1. The complete view of the UAV without mountings

2.2.1 Aerodynamics Study

The aerodynamics design of the UAV wing has been completed in the commercial design software AutoCAD 2017 and the design has been simulated using the simulation software ANSYS 15.0 Fluent solver. The study has been done to investigate the appropriate angle of attack for NACA 4414 airfoil to maximize the efficiency. The steps followed in our simulation process is briefly discussed below:

2.2.1.1 CAD Model Description

The wing profile is initially generated on AutoCAD 2017 and later imported into ANSYS 15.0 Design Modeler. A flow domain has been created around the wing surface which can be considered as a virtual wind tunnel. The Fig. 2.2 shows the designed CAD model.

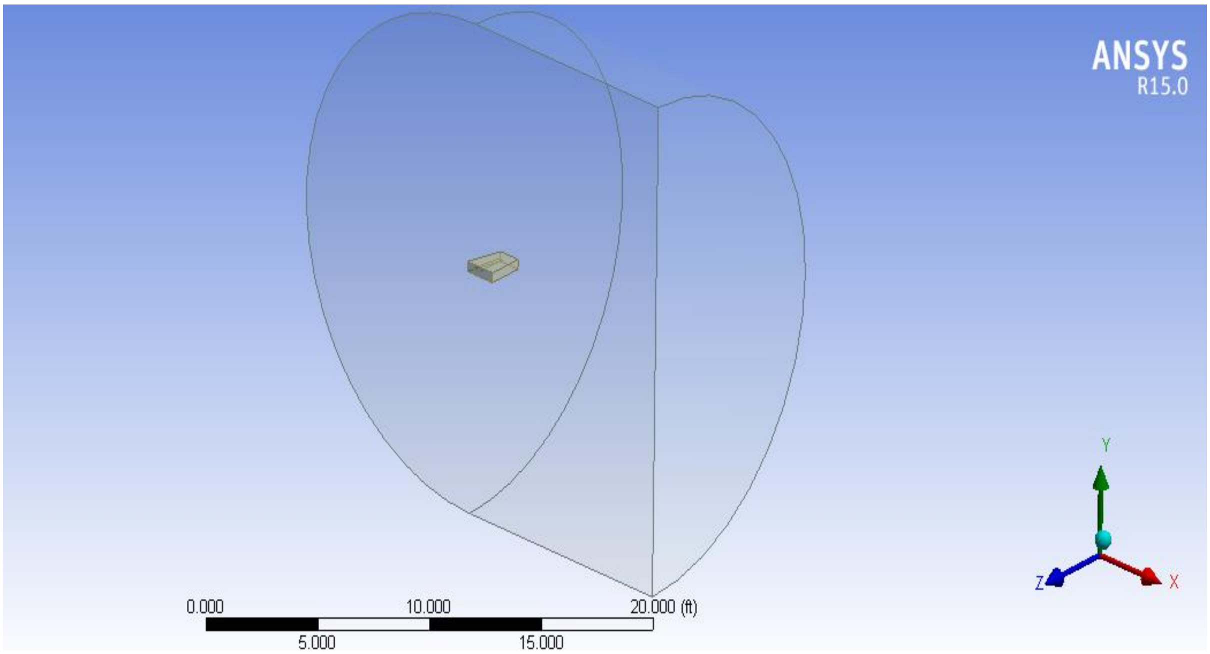

Fig.2.2 CAD model geometry of the project

2.2.1.2 Mesh generation in ANSYS

The triangular shape surface mesh with lower skew ness and higher orthogonal quality has been used due to its proximity to changing curves and bends. These elements easily adjust themselves to the complex bodies used in automobile and aerospace applications. With technical changes in the ANSYS ICEM CFD Meshing, the generated meshing for the sports car with rear wing can be visualized in the image (Fig. 2.3) provided on the other page. The image shows isometric view of the meshing for better understanding about mesh generation. The CAD geometry of NACA 4414 airfoil wing has 53, 128 nodes and 2, 59, 377 elements.

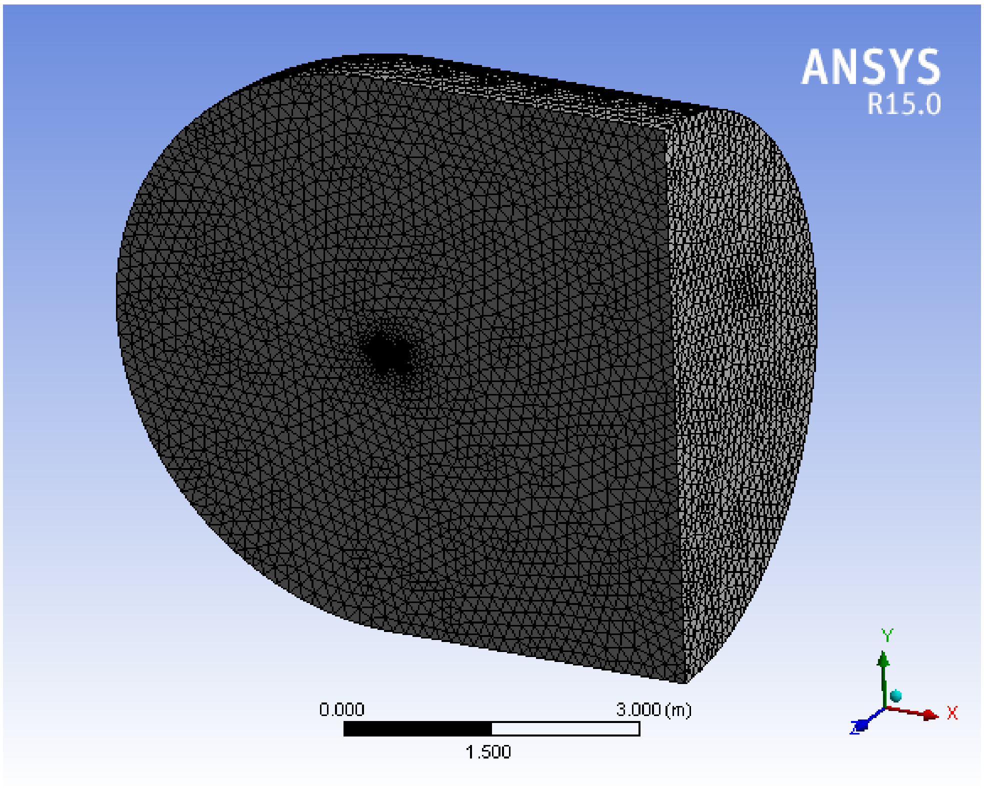

Fig.2.3 Mesh generation on the geometry model

2.2.1.3 CFD study & results:

Aerodynamic study of air flow over a body can be executed using CFD approach or analytical method. On one hand, analytical method of solving air flow over an object can be done only for simple flows over simple geometries just like laminar flow over a flat plate. If the flow of air gets complicated as in flows over a bluff body, the flow becomes turbulent and it is impossible to solve Navier- Stokes and continuity equations analytically [6]. Favre-averaged Navier-Stokes equations are used here, where time-averaged effects of the flow turbulence are considered. Flow simulation is employed using Spallart –Allmaras Model. Several steps have been taken for setting up the solving techniques in FLUENT solver for 3D, steady state, incompressible flow using serial processing technique. The inlet velocity condition has been given input as 40 km/h and outlet condition has been kept as a pressure outlet of 0 Pa (Gauge pressure). The CFD study has been done for 3° and 6° of angle of attack. The solution procedure has been initialized using hybrid initialization and the numerical solution has been done for 250 iterations with the reporting interval of 1. Table 1 summarizes the obtained results in this CFD study. From this study and review of several literatures [7-8], 6° angle of attack has been found to be efficient for this airfoil wing design.

Table 1. Analysis of lift force and drag force for 3° and 6° angle of attack

Angle of attack for wing	C_L	Lift force (N)	C_D	Drag force (N)
3°	0.02245	1.62	0.00258	0.18
6°	0.0309	**2.24**	0.00347	0.25

2.2.1.4 Dihedral effect

In this project, 6° dihedral angle has been kept to create dihedral effect. Dihedral angle has a strong influence on dihedral effect, which is named after it. Dihedral effect is the amount of roll moment produced per degree (or radian) of sideslip. Dihedral effect is a critical factor in the stability of an aircraft about the roll axis (the spiral mode). It is also pertinent to the nature of an aircraft's Dutch roll oscillation and to maneuverability about the roll axis. Fig. 2.4 shows the dihedral angle in our design.

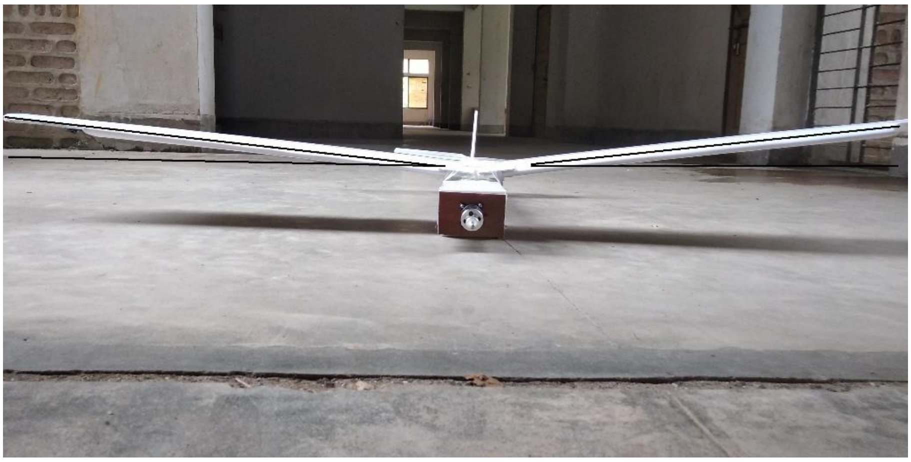

Fig.2.4 Dihedral effect of the wing

2.2.2 Mechanical Components

2.2.2.1 Depron Foam Board

Three depron foam boards of 4ft.*5ft. with a thickness of 3 mm have been used to build the body of the UAV. Depron is a foam sheeting normally used for things like underfloor heating but found fame some time ago when it was introduced to the indoor flying scene by the Icarus Shockflyer range. Depron has an excellent strength to weight ratio. Fig.2.5 shows an image of a depron foam board.

Fig.2.5 Depron foam board (white color)

2.2.2.2 Ply wood

A piece of plywood of 3 mm. has been used in this project to mount the BLDC (Brass Less Direct Current) motor easily. The figure 2.6 shows a piece of plywood.

Fig.2.6 A piece of plywood

2.2.2.3 Propeller

A 10*4.5 inch black color propeller has been used in this project. Propellers create thrust through the rotating shaft of BLDC motor to create enough lift.

Fig.2.7 Propellers used in UAV

2.2.2.4 BLDC motor

A BLDC (Brass Less Direct Current) motor of 1100 kV and 12500 rpm has been used in our project. The propeller is connected to the shaft of the BLDC motor.

Fig.2.8 BLDC motor

2.2.2.5 Servo motor

Three pieces of Tower pro 9gm servo have been used in our project to control elevation, rudder and object dropping mechanism in the project.

Fig.2.9 Servo motor

2.2.2.6 Stainless steel wires

Stainless steel wires have been used in this project to complete the several mechanisms of this project. One end of the steel wire is connected to the servo motor controlling arm and another end is connected on the desired place to create and control mechanism.

Fig.2.10 Stainless steel wire

2.2.3 Electrical Components

2.2.3.1 Arduino Mega 2560

The Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila. It is to be noted that the Arduino Mega in this project has been used to program the Electronic Speed controller and the board has no connection with the circuit diagram of the UAV.

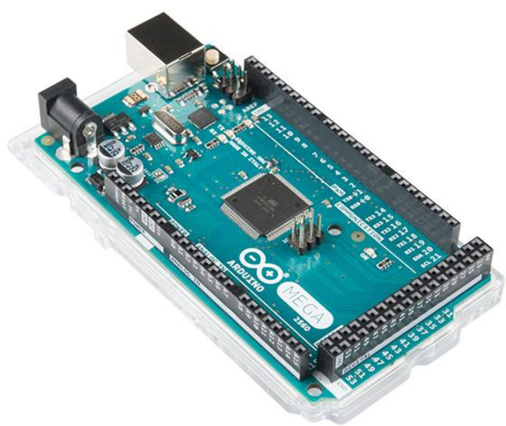

Fig.2.11 Arduino Mega 2560

2.2.3.2 Electronic speed controller

The prime task of Electronic Speed Controller (ESC) is to control speed of the BLDC motor. Wires of one end of the ESC are connected to the BLDC motor and other end is connected to the receiver of the radio controller. ESCs are programmable using the Arduino Mega board. The details of the programing is shared in the appendix of the project report.

Fig.2.12 Electronic speed controller

2.2.3.3 Low voltage buzzer

A low voltage buzzer has been used in this project to ensure flight and battery safety. A low voltage buzzer has an alarm system in itself which buzzes when significant amount of voltage is lacked in the power supply source i.e., battery.

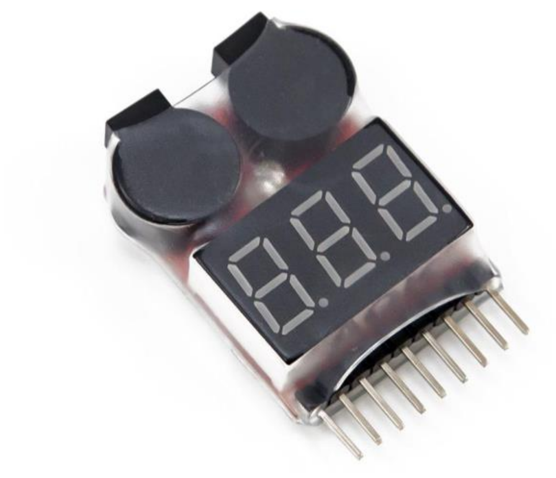

Fig.2.13 Low voltage buzzer

2.2.3.4 Radio controller & receiver:

Flysky Fs-i6 radio controller & receiver has been used in the project. The FlyskyFs-i6 receiver works perfectly in 2.4 GHz band and has a working radius of approximately 500 meter from center.

Fig.2.14 Radio controller & receiver

2.2.3.5 Li-Po Battery:

We used a 11.1V-2200mah three cell LiPo battery as power source. It is a lithium polymer battery or more correctly lithium-ion polymer battery. It is a rechargeable battery of lithium-ion technology in pouch format.

Fig.2.15 Lithium Polymer ion battery

2.2.3.6 Vero Board:

We have used solder able vero board for interconnecting the electrical components. It gave us the freedom of not using complicated PCB boards.

Fig 2.16 Vero board

2.2.3.7 HD Camera:

An EKEN H9R Action camera has been used in this UAV to use it as a mounting on the UAV. EKEN H9R can take continuous pictures, videos on 4K and HD (High definition) resolution. It has built in Wifi and HDMI output. It has a waterproof housing which works up to 100 feet deep. The camera has a 2 inch Full HD display.

Fig. 2.17 HD Action camera

2.2.4 Components used for connections

We used different types of things for connecting the mechanical and electrical components to make chassis and circuit of the robot. The list of these items are as follow:

- Jump Wires (Male to male, male to female, female to female)
- Connecting Wires
- Glue Gun (For joining electrical components with the acrylic sheet)
- Both Sided Tape
- Nut and Bolts
- Highter
- Soldering Iron

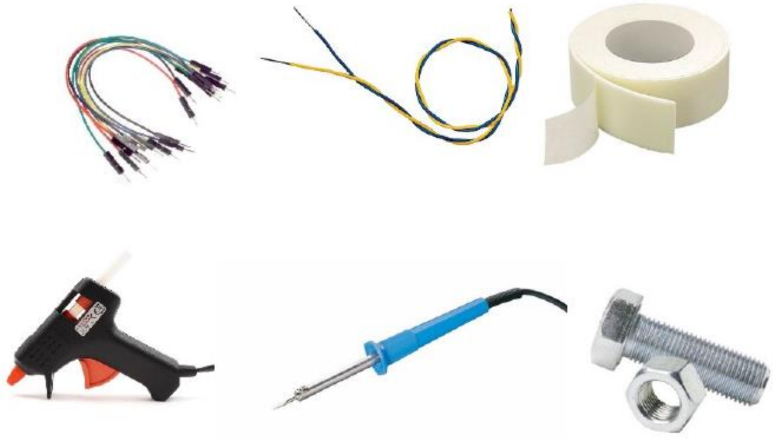

Fig.2.17 Components used for connection

2.2.5 Softwares used

The softwares we used during this project are:

- AutoCAD 2017
- Arduino
- ANSYS

2.3 Basic working principle

There are several principles that should be followed to make a drone could work smoothly. The first principle is communication. This is a principle related to the communication between the vehicle with the control headquarter or ground system. In applying this principle, most device employs Radio Frequency. Besides controlling the aerial vehicle, this radio frequency can also be used in data transferring from the sensors to headquarter. In our project, a radio controller has been used to keep all types of communication.

The second one is loop principle. Most of the drone devices using close-loop, open-loop, or even hybrid loop. The open loop here provide the positive control (left, right, slow, fast, up, down) of the signal without needing feedback from sensors. While the close-loop, it employs feedback from the sensors to adjust the action (increasing and decreasing speed, moving altitude, etc.) to the recent condition. In our project, the open loop principle has been employed.

The last principle is Flight control, this is the similar principle in manned aviation. It controls something like flight dynamics, automation and unautomation, multi rotor dynamics of the flight, and other parameters. Through this principle, we can set the drone to do certain maneuver, landing, perching, and climbing. This principle had been followed in our project although flight control solely depends on remote control system.

2.4 Circuit Diagrams

2.4.1 Circuit Diagram of UAV system:

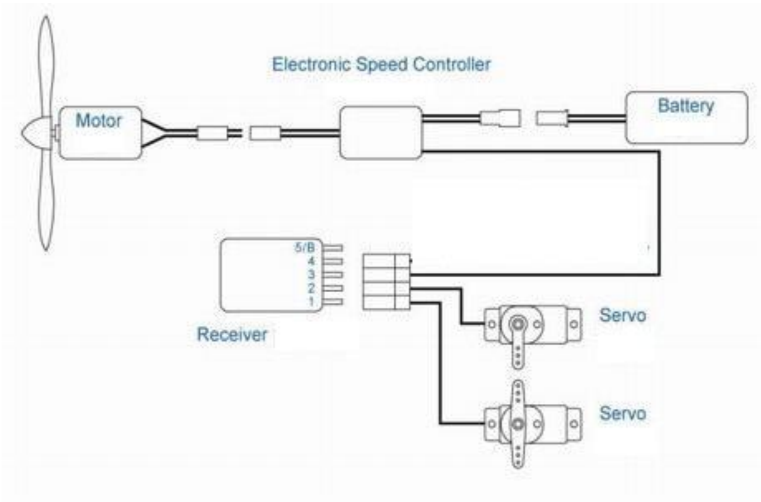

Fig.2.18 Circuit diagram of an Unmanned Aerial System

2.4.2 Connection between Arduino & ESC for programming purpose

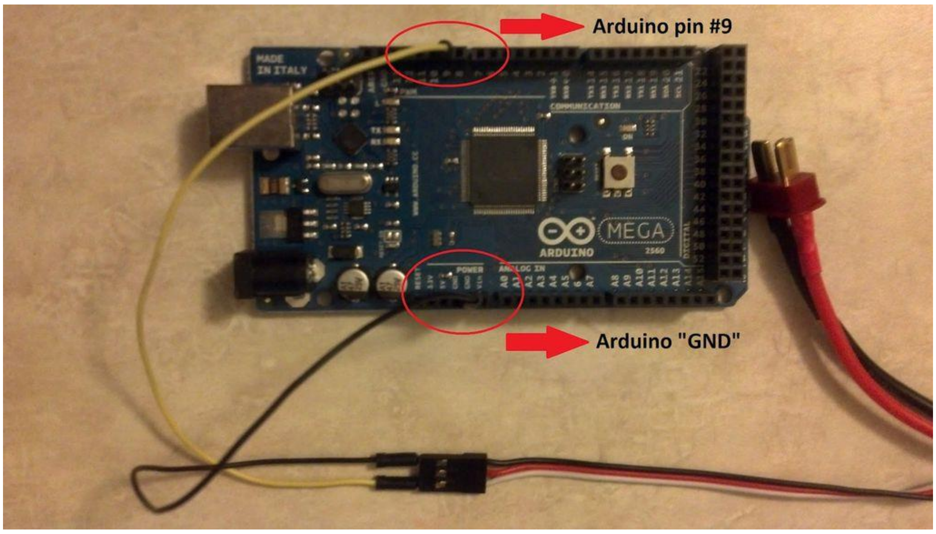

Fig.2.19 Connection between Arduino & programmable ESC

Chapter 3

Solution Validation, Analysis of Data, Results

3.1 Solution validation:

As it is discussed earlier, the whole UAV has been initially designed and simulated in software like AutoCAD 2017 and ANSYS 15.0. The outcomes of this study has been later reproduced as the prime design parameters of the actual UAV design. Our mechanical part worked very well during test flights. The remote controlled communication between the UAV and the remote controller has worked perfectly. All the common movements of the UAV such as throttle, rudder and elevator has worked smoothly. We have worked with different flight conditions with different maneuvers. The UAV has been tested with different payloads.

3.2 Analysis of Data

Flight data retrieved from remote controller system has been used to analyze the flight performance. There had been higher throttle control at the beginning which led to us several fatal crashes and thus, the throttle of the remote control system was constrained to 50%.

The remote control we used has a range radius of 500 meter. But in this project, we have used the remote control system in such a way so that we can keep the UAV within our visual range. Thus, the maximum controlling distance was within 250 meter.

3.3 Results:

The UAV has successfully implemented its assign task during the test flights: capturing footage and object dropping. The control over the UAV has been found to be significant. But from our experience, it is to stated that, piloting skill is very vital to control such unmanned aerial systems. As this UAV design dosen't have a flight controller on board, the stability of the UAV is manually controlled and hence piloting skill is very important. The results we got from the tests were very positive and encouraging. A footage of successful flight test is given on the next page of the project report. The conclusion that has been drawn from the project is given below:

- From our experience to build copter type UAVs in past, the performances have been compared and this fixed type of UAVs require more piloting skill.
- The mechanical design is very light and there is no sharp edge in the body which adds to the safety of the people around it.

- The mechanical and electrical components which we used are not very expensive which makes this project cost effective.

Fig.2.20 Successful Flight of the UAV

Chapter 4

Limitations, Conclusion and Recommendations

4.1 Limitations:

We tried our level best to add maximum features to our project 'Fixed Wing Unmanned Aerial Vehicle. But still there are some limitations in our project.

- There is no flight controller board on the UAV and thus the stabilization during the fly has to be done manually and requires great pilot skill.
- At a time only one person can connect with the UAV and control the system.
- The range of the remote control system is on or around about 500 meters (1500 feet). Anyone out of this range will not be able to connect with the UAV.

4.2 Recommendations:

To draw the end of this discussion, we can simple say that there is always space for the improvement. The further improvements which can be done are as follow:

- Flight controller or self stabilizing gyro system should be added to have better control of this Unmanned Aerial System.
- For bigger range, Global Positioning System can be introduced.
- Number of applications can be increased by adding more sensors and actuators.
- By improving the mechanical design, adding some extra safety precautions and using extra electrical components we can implement this idea in real life military usage.

4.3 Conclusion:

To complete the project we gave our best effort and as a result got this outcome. Our course teachers were very encouraging and inspirational. Their proper guideline and our hard work made this project possible. Though there are some limitations in the project, these can be avoided by further improvement.

This course ME 368 was quite a different and exciting course for us. It gave us the opportunity to express our talent. This course taught us how to tackle with practical life problems and how to overcome them. After all this was a great experience for all of us.

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Appendix

Arduino code to program Electronic Speed Controller

```
*/
#include <Servo.h>


int value = 0; // set values you need to zero

Servo firstESC, secondESC; //Create as much as Servo object you want and can be controlled 
2 or more Servos at the same time

void setup() {

  firstESC.attach(9);    // attached to pin 9 I just do this with 1 Servo
  Serial.begin(9600);    // start serial at 9600 baud

}

void loop() {

//First connect ESC WITHOUT Arming. Then Open Serial and follow Instructions

  firstESC.writeMicroseconds(value);

  if(Serial.available())
    value = Serial.parseInt();    // Parse an Integer from Serial

}
```

Understanding & Programming an ESC

The introduction for the setting of programming

The setting of programming :(the five following warning tone is as follows.)
A= - beep- short sound
B= beep-beep-beep 3 three continuing sounds
C=~beep gradual changing sound+beep
D= beep↘ low sound
E= beep-- long sound

music1	throttle		A-A-A-A
music2	brake		B-B-B-B
music3	types of battery	**nickel-hydrogen battery**	C-C-C-C
music4		**lithium battery**	D-D-D-D
music5	protection threshold for low voltage	low	E-E-E-E
music6		middle	AA-AA-AA-AA
music7		high	BB-BB-BB-BB
music8	Recover to factory default setting		CC-CC-CC-CC
music9	Angle of entrance	Automatic	DD-DD-DD-DD
music10		Low	EE-EE-EE-EE
music11		High	AAA-AAA-AAA-AAA
music12	Startup of motor	Ultra smooth	BBB-BBB-BBB-BBB
music13		Smooth	CCC-CCC-CCC-CCC
music14		Accelerated startup	DDD-DDD-DDD-DDD
music15	Mode for helicopter	Turn off	EEE-EEE-EEE-EEE
music16		The helicopter mode 1	AAAA-AAAA-AAAA-AAAA
music17		The helicopter mode 2	BBBB-BBBB-BBBB-BBBB
music18	The pros and cons setting of motor rotation		CCCC-CCCC-CCCC-CCCC
music19	PWM frequency of motor	8K	DDDD-DDDD-DDDD-DDDD
music20		16K	EEEE-EEEE-EEEE-EEEE
music21	Protection mode under low voltage	Reduce power	AD-AD-AD-AD
music22		cutoff output	AE-AE-AE-AE