ANUAR AHMAD SALAR MASTER OF SCIENCE IN ENGINEERING (AERONAUTICS) UPNM 2019

# FLIGHT DYNAMIC MODELLING OF A MICRO QUADCOPTER UAV

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**MASTER OF SCIENCE IN ENGINEERING (AERONAUTICS)**

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# FLIGHT DYNAMIC MODELLING OF A MICRO QUADCOPTER UAV

**ANUAR BIN AHMAD SALAR**

Thesis submitted to Centre for Graduate Studies, Universiti Pertahanan Nasional Malaysia, in fulfillment of the requirements for the Degree of Master of Science in Engineering (Aeronautics)

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# ABSTRACT

This project will study the characteristic of flight dynamic modelling for the Micro Quadcopter UAV. The aim of this study is to identify the flight characteristic of the Micro Quadcopter UAV which has all four basic control surfaces (Roll, Pitch, Yaw and Thrust). The benefit of this project is to have a natural flight dynamic modelling of the Micro Quadcopter. The study will be in 2 parts, testing by using experimental (Flight Dynamic Testing) and simulation tool by using MATLAB. The simulation is designed to simulate the following. Lastly, validate the designed transfer function and analysed the performance of the Micro Quadcopter UAV.

# ABSTRAK

Projek ini adalah untuk mengkaji ciri-ciri pemodelan dinamik penerbangan untuk Micro Quadcopter UAV. Objektif utama kajian ini adalah untuk mengenalpasti ciri-ciri penerbangan dari Micro Quadcopter UAV yang mempunyai empat permukaan kawalan asas (Oleng, Anggul, Rewang dan Tujahan). Manfaat projek ini adalah memperolehi pemodelan dinamik penerbangan semulajadi terhadap Micro Quadcopter UAV. Kajian ini dilaksanakan dalam dua bahagian. Bahagian pertama adalah melaksanakan ujian penerbangan (Flight Dynamic Testing) manakala bahagian kedua adalah adaptasi ujian penerbangan dengan menggunakan perisian simulasi iaitu MATLAB. MATLAB adalah berfungsi untuk mensimulasikan permodelan dinamik penerbangan terhadap permukaan kawalan asas Micro Quadcopter UAV. Akhir sekali, pengesahan projek dengan menggunakan simulasi fungsi tranfer yang telah direkabentuk dan dianalisis berhubung prestasi Micro Quadcopter UAV.

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# EXAMINATION COMITTEE APPROVAL

The Examination Committee has met on **2nd February 2019** to conduct the final examination of **Anuar bin Ahmad Salar** on his degree thesis entitled **'Flight Dynamic Modelling of a Micro Quadcopter UAV'**

The committee recommends that the student be awarded the Master of Science in Engineering (Aeronautics)

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DECLARATION OF THESIS

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| Title | : Flight Dynamic Modelling Of A Micro Quadcopter UAV |
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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Nowadays, the development of small UAV is fascinated by many researchers and wanting to explore the application. Currently, there is a large range of projects and research topics emerging in this field. Preliminary research has shown that the most versatile and mechanically easy to construct UAV is a quadrotor helicopter. This is because the quadrotor aerial robot is an automatic system, which is an unmanned VTOL (vertical take-off and landing) helicopter. Quadrotors can be controlled by varying the speed of the four rotors and no mechanical linkages are required to vary the rotor blade pitch angles as compared to a conventional helicopter [1].

Unmanned Aerial Vehicles (UAVs) are a viable alternative to manned aircraft and satellites for a variety of applications, including environmental monitoring, agriculture, and surveying. They promise greater precision and much lower operating costs than traditional methods. Critical to the success of UAV systems is the auto-pilot system, which keeps the vehicle in the air and in control of the absence of a human pilot [2].

A quadcopter is a multirotor helicopter that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers). Quadcopters generally use two pairs of identical fixed pitched propellers; two clockwise (CW) and two counterclockwise (CCW) [3].

These used an independent variation of the speed of each rotor to achieve control. By changing the speed of each rotor, it is possible to specifically generate a desired total thrust; to locate for the centre of thrust both laterally and longitudinally and to create a desired total torque, or turning force. A Quadcopter UAV configuration is as shown in Figure 1[3].

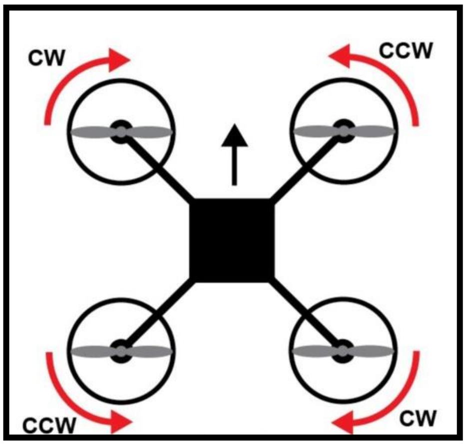


**Figure 1:** The Micro Quadcopter UAV Configuration.

The aim of this study is to identify the flight characteristic of the Micro Quadcopter UAV, which has all four basic control surfaces (Motor 1, Motor 2, Motor 3 and Motor 4) as shown in Figure 2.

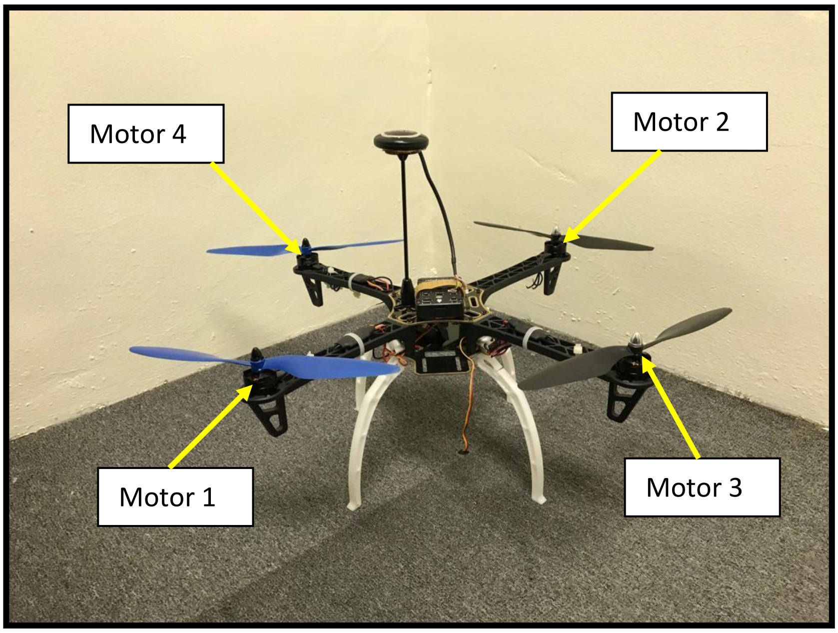


**Figure 2:** The Micro Quadcopter UAV Model.

The overall objective of this project is to design a flight dynamic model for the Micro Quadcopter UAV. This paper will discuss two major parts in designing the Micro Quadcopter UAV's flight dynamic model which are:

a. Basic components (hardware) and software of the Micro Quadcopter UAV.

b. Micro Quadcopter UAV modelling validation.

A flight dynamics model is a mathematical representation of the steady-state performance and dynamic response that is expected of the proposed vehicle, in this case, the Micro Quadcopter UAV. The uses of flight dynamics model are diverse [3].

The fundamental goal of flight dynamics modelling is to represent the flight motion numerically for a given input, as close to the flight motion in the real world, as the application requires. To accommodate a wide range of applications, various implementations of flight models in terms of assumptions and algorithms are needed, therefore, exist [3].

Nevertheless, all flight dynamics models are based on the mathematical model derived from Newtonian Physics. The Micro Quadcopter UAV will be integrated with multiple sensors for the testing purposes. The multiple sensors are:

a. 3-Axis gyroscope.

b. 3-Axis Accelerometer.

c. Barometric sensor.

d. Magnetometer (compass).

e. Air-speed indicator.

f. GPS module.

The expected result from this project will be the unique information in identifying the natural characteristic of the Micro Quadcopter UAV.

## 1.2 Problem Statement

There are many types of Micro Quadcopter UAV developed by the UAV industries for a broad field of application. Some of the Micro Quadcopter UAV are design conventionally, downscale from a real aircraft, and some design unconventionally to suit its mission and application. May it be the conventional or non-conventional type of the Micro Quadcopter UAV, the control system for the Micro Quadcopter UAVs remains the same, simple yet working.

Basically, the Micro Quadcopter UAV will depend on its attitude (roll, pitch and yaw) rate of change for the control feedback loop. This is done by using an angular rate gyro to determine the attitude rate of change for the Micro Quadcopter UAV. This is differing to a conventional fixed-wing aircraft, where it utilized more than attitude rate change for the control feedback. A conventional fixed-wing aircraft required the side slip angle and angle of attack measurement (aside from the attitude rate of change) to give a better performance in designing its control loop.

However, if the Micro Quadcopter UAV has the capability like a conventional aircraft, it can perform better and able to be flown in a harsher environment. For example, an aircraft required to fly at a certain side slip (off of its axis) and it is very difficult for a pilot to maintain flying at a sideslip, thus a control loop is designed to automatically put the aircraft on a side slip whenever there is a crosswind. The same thing can be done for the Micro Quadcopter UAV. With the side and roll measurement, the Micro Quadcopter UAV can be automatically fly in a heavy crosswind.

## 1.3 Objectives

a. To develop and test a flight dynamic model for the Micro Quadcopter UAV.

b. To identify and model the natural characteristic of the Micro Quadcopter UAV.

c. To verify the flight dynamic model for the Micro Quadcopter UAV.

## 1.4 Research Scope

a. Scope of Work

(1) Mathematical Model for the Micro Quadcopter.

(2) Modelling and simulation by using MATLAB.

(3) Verification of the model by experimental testing.

(4) Using small size UAV.

(5) Using Quadrant UAV.

b. Limitations

(1) The simulation modelling does not cover all of the flight phases of the UAV, especially on the take-offs and landings.

(2) Constant thrust was being used throughout the flight test.

(3) Thrust exerted were too sensitive; thus only 30% of throttle was used.

## 1.5 Thesis Outline

This project has been divided into five main sections which are introduction, literature review, methodology, results and discussion, and conclusion:

**Chapter 1**. This section presented the importance of this research as well as the main motivation to carry out this work.

**Chapter 2**. *Literature Review* is provided in this section, where the overview of the basic principle of the Micro Quadcopter UAV is discussed.

**Chapter 3**. *Methodology*, which explained how the project will be carried out. The project began by explaining the mathematical modelling of the joint based on using Newton-Bernoulli flight theory. Then, the mathematical modelling equations provided with the parameters for solving and simulating the Micro Quadcopter UAV. The mathematical equations with the parameters of the Micro Quadcopter UAV are then solved by using MATLAB codes.

**Chapter 4**. *Result and Discussions* presented and analysed the results from the MATLAB simulations through varying some of the parameters and variables as stated in Chapter 3 (Methodology).

**Chapter 5**. Concluded and summarized the work by providing the flight dynamic model for the Micro Quadcopter UAV. Recommendation for future works is also included in order to enhance flight dynamic model for the Micro Quadcopter UAV.

# CHAPTER 2

# LITERATURE REVIEW

In this modern world, there is a broad application of UAV in multiple fields of operation aside from war. For example, UAV is used for large crops size fertilizing and watering in agriculture industries. UAV has also been used as monitoring means for structure observation in construction industries. Some country such as Canada has utilized the UAV for a domestic high-risk role including surveillance, patrolling and environment monitoring. In the defence area, UAV can be used in both surveillance and as a weapon platform. This is possible as the payload of the UAV can be changed to suit its application, but the basis of the UAV remains the same; flyable and controllable [1].

Most of the UAV developed in the world was designed to be as simple as possible with a small number of sensors in order to increase the number of payloads that can be mounted onto the UAV and also to decrease the complexity of computation by the controller onboard the UAV. This is because the same controller is used for other functions such as data transmission and data processing that is required by the UAV operation. The small number of sensors is good enough for the UAV to operate in a normal condition and it also allows a simpler feedback controller to be designed for the UAV [2].

The main objective of this thesis is to develop and test a flight dynamic model for the Micro Quadcopter UAV. Implementing a flight model in MATLAB is generally the first step towards development. MATLAB provides comprehensive modelling tools that allow concepts to be quickly validated and fine-tuned for improvements [3].

## 2.1 NATO Classification for UAV

The UAV chose for this thesis is Micro Quadcopter UAV. The model type is DJI 450 with 1.45kg and a single operator only. NATO Classification are shown in Table 1: [15]

**Table 1:** NATO UAS Classification Guide.

**NATO Classification**

| Class & Weight, w (kg) | Category & Weight , w (kg) | Normal Employment | Normal Operating Altitude, h (ft) | Normal Mission Radius (km) | Example Platform |
|---|---|---|---|---|---|
| Class I $w < 150$ | Small $w > 20$ kg | Tactical Unit (employs launch system) | $h \leq 5000$ AGL | 50 (LOS) | Luna, Hermes 90 |
| | Mini $2 \leq w \leq 20$ kg | Tactical Unit (manual launch) | $h \leq 3000$ AGL | 25 (LOS) | ScanEagle, Skylark, Raven, DH3, Aladin, Strix |
| | Micro $w < 2$ | Tactical Patrol/section, Individual (single operator) | $h \leq 200$ AGL | 5 (LOS) | Black Widow |
| Class II $150 \leq w \leq 600$ | Tactical | Tactical Formation | $h \leq 10{,}000$ AGL | 200 (LOS) | Sperwer, Iview 250, Hermes 450, Aerostar, Ranger |
| Class III $w > 600$ | Strike/ Combat | Strategic/ National | $h \leq 65{,}000$ | Unlimited (BLOS) | |
| | HALE | Strategic/ National | $h \leq 65{,}000$ | Unlimited (BLOS) | Global Hawk |
| | MALE | Operational/ Theater | $h \leq 45{,}000$ MSL | Unlimited (BLOS) | Predator A, Predator B, Heron, Heron TP, Hermes 900 |

## 2.2 Components of the Micro Quadcopter UAV

a. The Body/Frame

The frame or body is what holds everything together. They are generally designed to be strong and lightweight and consist of a centre plate, where the main flight controller chip and sensors are mounted and arms where the motors are mounted. Usually, it is made of carbon fibre, fibreglass, aluminium or steel. Some cheaper, smaller models also use plastic. The frame comes in varieties for different multirotor types: Tricopter, quadcopter, hexacopter, octocopter. It also varies on different builds, depending on whether it is used for aerial photography, FPV drone racing, etc [4][5].

b. Motors

The motivation behind using motors is to turn the propellers, which is responsible for providing thrust for countering gravity and drag. Every rotor bought to be controlled separately by a speed controller. Motors are the primary force behind how a quadcopter fly [4].

They are somewhat like the typical DC motors in the sense that coils and magnets are utilized to drive the shaft. The brushless motors do not have a brush on the shaft that deals with iterating the power in the coils, hence, the 'brushless' reference [5].

The brushless motors have 3 coils on the inside centre of the motor, which is settled to the mounting. On the external side, it contains multiple magnets mounted to the cylindrical structure that is appended to the turning shaft.

Hence, the coils are fixed and there is no need for brushless. Brushless motors turn a lot quicker and utilize less power at the same speed relative to the DC motors. Unlike DC motors, they do not lose power in the brush-transition, so it is a lot more vitality productive.

The Kv (kilovolts) – rating in a motor demonstrates how various RPMs (Revolutions each moment) the motor will do per volt. The higher the kV rating is, the quicker the motor rotates at a steady voltage [6].