Identification of Damping Coefficient for Unmanned Aerial Vehicle Based on Wind Tunnel Test Section

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Abstract:

Flight testing has become more significant for determining in the form of derivatives, flight data can be used to determine stability and control characteristics and other behavior factors. As new aero plane concepts are developed and the aircraft flies in new Mach and altitude regimes, Verification of theory and wind tunnel data is required, as well as to identify the reasons of inconsistencies between forecast and actual flight behavior, to provide data not gained in wind-tunnel tests, and to provide data not acquired in wind-tunnel tests. There are examples of using flight derivatives to confirm predictions and establish aero elastic effects, stability criteria, and flight guiding. A substance's damping coefficient affects whether it will rebound or recover energy to a system. A high damping coefficient will lessen the reaction, meaning it will absorb the energy and diminish the system's responsiveness, if an undesired vibration or shock causes the bounce. The changing relative airflow creates a restoring moment whenever manoeuvres result in rotation of an aircraft about or near its centre of gravity. This restoration instant rejects control demands and halts manoeuvres when control demands are no longer present. The dynamic pressure determines the restoring moment's efficiency (also known as aerodynamic damping) (i.e., indicated air speed).

Keywords: Unmanned Aerial Vehicle, Wind Tunnel, Aerodynamic, Damping

1. INTRODUCTION

The first step is installing a control system of Fixed Wing Unmanned Aerial Vehicle is to use a mathematical model to characterise the UAV's behaviour. The technique of controller design, which is the identification of the parameters of the equations, is required to achieve this exactly for the specific UAV. The act of constructing mathematical models is known as system identification for physical systems based on faulty observations or measurements. This technique is known as aircraft system identification if the physical system is an aircraft. It's used to simulate unknowns using previously obtained data.

This research article aims to develop a prototype of an Unmanned Aerial Vehicle (UAV) with fixed wings. The model or prototype we will made will be the one on which we will do the tests or experiments will be done in order to acquire the essential results. The size of the UAV will be according to our subsonic wind tunnel test section. So that the UAV that will be built may be readily put into the wind tunnel's test section to conduct the tests. In the subsonic wind tunnel phase, we'll conduct the necessary tests and experiments to collect the information needed for future computations and purposes. In the wind tunnel, from the tests we will obtain the results and concludes the project accordingly by comparing them with the each other. The tests will be made to obtain the deflections of the aircraft with the help of the Inertial Measurement Unit (IMU) which consists of the Accelerometer, Gyro meter, Magnetometer and Thermometer. The Inertial Measurement Unit and the Unmanned Aerial Vehicle will be connected through the Arduino. Through the Arduino software in the computer, the controls will be given to the UAV to deflect the ailerons, elevators and rudder.

A parameter estimation problem is usually formulated as an optimization one. Small-scaled Fixed wing Unmanned Aerial Vehicle is using for security monitoring & battle are less expensive than Big size & high altitude Unmanned Aerial vehicles, offer significant benefits in civilian and military fields. Due to their Compact UAVs could conduct close supervision in a discrete and adaptive manner due to their less mass, low space consumption, and simple take-off [1]. Prior to creating any assignment, the model of Aircraft should be built. Small-scaled Fixed wing Unmanned Aerial Vehicle is having structure parameters, such as Wing Span, Mean Aerodynamic Chord Length, and Reference Area should be computed with accuracy. Here, D stands to propeller diameter, rotation rate, and airspeed. [2] can all be used to calculate the thrust generated by the propeller. However, despite their relevance in estimating force and moment, aerodynamic properties, such as stability and control derivatives, are fairly difficult to obtain. In relation to control input, control derivatives utilize partial derivatives, whereas stability derivatives take complete derivatives employ partial derivatives in relation to states. Static stability derivatives are used for air-relative velocity variables, whereas dynamic stability derivatives are utilised for angular rates and unstable aerodynamics [3]. Wind tunnel experiments or CFD software are commonly used to examine aerodynamic parameters, however both are insufficient for small aircraft. Wind tunnel experiments are costly and takes more time [4], and the results in low Reynolds number flight circumstances are frequently erroneous. Furthermore, in most CFD software evaluations, meshing the 3D model takes a long time, and the gap effect and frictional drag are frequently overlooked [5]. Another option for parameter calculation is Data Compendium (DATCOM), which was developed by the US Air Force. When the appropriate parameters are loaded, all of the aerodynamic coefficients can be acquired from the massive flight database. However, there are certain disadvantages to DATCOM. The input parameters are difficult [6], and the angle-of-attack computational interval will influence the analysis, as a result, small UAVs have limited precision. [7].

Based on aerodynamic theory there is a method of semi empirical that may be used to estimate the longitudinal and lateral derivatives sequentially using semi-empirical formulas or diagrams, taking into account the unique aerodynamic design and flight conditions of small UAVs. Arifianto's research [8] also referenced the semi-empirical technique. The flight data for C_W, for example, is based on a hypothesised link between the wing's geometrical shape & Low Mach number. Assumption of low angle of attack is measuring, structure and low Mach number are made to uncomplicate the aero dynamic analysis of the modest aircrafts. The small Mach number, simple aerodynamic structure, and small angle-of-attack assumption, Small-scale aircraft aerodynamic analysis is typically simplified. As a result, in the study, this type of semi-empirical method will be used to logically determine the starting parameters is very short period of time taking and at a Reasonable cost only. Although semi-empirical analysis is a useful technique, the accuracy of the parameters is occasionally called into doubt due to structure simplification and changes in flight conditions. The aerodynamic parameters are virtually all constants after the conceptual computation, Given the small Mach number criterion and moderate angle-of-attack assumption, it makes logical. This suggests that the approach does not perform well in real-time. As a result, utilising real-time flight data, the identification technique is employed to compensate for the error in aerodynamic properties.

In general, there are numerous approaches for finding or estimating aerodynamic variable error that can be classified as off-line or on-line. Here Error approach of Formula and the result Error method are examples of offline methods. The former applies the Least Squares (LS) approach, whilst the later makes use of the Probabilistic Method. The Off-line methods should be applied both the temporal and frequency domains [9,10]. A neural network's structure has also been used to define or recognize the dynamic behaviour of aircraft [11,12]. All of the methods outlined above require a significant quantity of calculation and the collecting of all precise dimensions that correspond to states of the system.

2. FABRICATION OF UAV

2.1 Low Speed Wind Tunnel Test Conditions:

The prototype was tested in a 0.6x0.6x2 low-speed subsonic wind tunnel section with a changeable speed range of 10-50 m/sec. By using an electronic actuator, the motor drive unit may quickly change the tunnel speed. Control surfaces (elevator, ailerons, and rudder) were moved longitudinally, laterally, and directionally by servo motors on this prototype. By measuring the corresponding deflection to the known inputs, these control inputs were delivered to servos utilising lab view software. The positions values(deflections) of the pitch, roll and yaw of the aircraft will be attained by Inertial Measuring Unit (IMU).

Fig. (1). UAV Prototype

Because there will be some error in control deflection due to aerodynamic stresses acting on the surface, potentiometers are commonly utilised to measure the actual deflection of the control surface to the provided input.

2.2 Arduino Connections:

The connections to Arduino uno board should be done carefully. Three servo motors has been used here to control the movement (deflections) of the control surfaces Ailerons, Elevators and Rudder. The connections are made in such way that the input voltage is given to servos through the 5V pin in the Arduino and in the same way ground connection has also been given. And the signal pins are connected in a way that pin 7 is connected to the Aileron controlling Servo motor, pin 8 is connected to the Elevator controlling Servo motor and the pin 9 is connected to the Rudder controlling Servo motor.

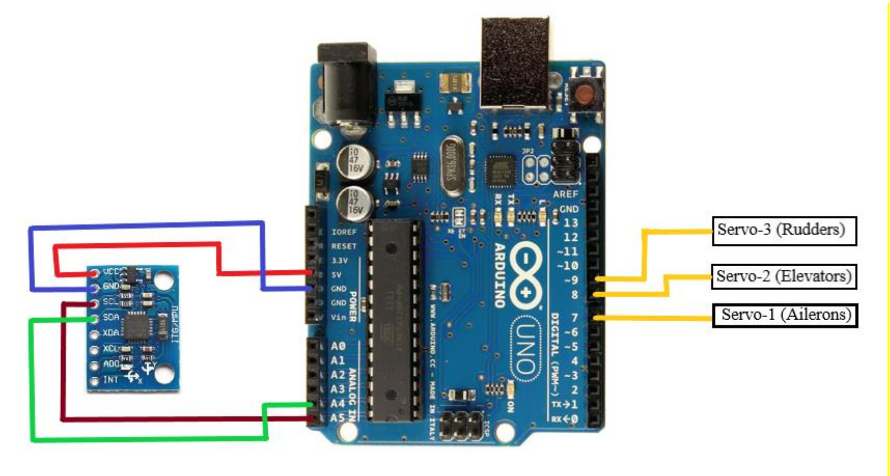


Fig. (2). Connections between Arduino UNO and IMU (MPU 6050)

In the Inertial Measurement Unit (IMU) we have used only the first four pin i.e., VCC, GND, SCL and SCA. The connections are made to Arduino board in such a way that VCC to the 5V, GND to GND, SCL to A5 and SCA to A4. The IMU plays a main role here, the output taken from the IMU while the UAV deflections has been used to know the deflections or damping of the overall UAV.

3. RESULT AND DISCUSSION

3.1 Damping Estimation System:

Damping is an important characteristic for aircraft resonant response. Damping is also important for structural dynamics. Because it is difficult to acquire dynamic damping response using a theoretical method, experimental inquiry has become the universal method for damping estimation. When a control input is applied to control surfaces, the airplane's equilibrium position is deflected and altered, and the aircraft regains a new equilibrium position after a period of time, either oscillating or in a linear manner. The damping characteristics of the aircraft can be assessed by reducing the angular velocities (energy) of the aircraft and determining whether it is critical, under, or over damped.

Along longitudinal direction:

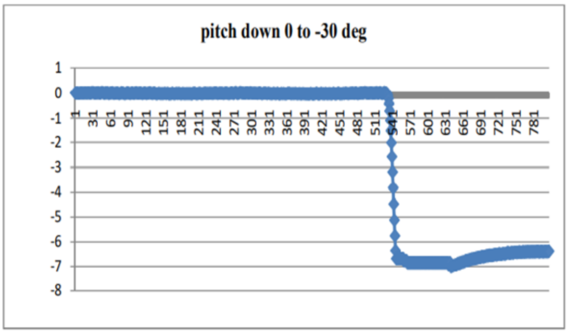
The damping derivatives is C_{mq},
Stability derivative is $C_{m\alpha}$,
Pitch control derivative is $C_{m\delta e}$,
Along lateral & directional:
Directional stability derivative is $C_{n\beta}$,
Dihedral effect derivative is $C_{l\beta}$,
Roll rate, C_{np} is the Yaw rate of Damping derivatives,
Yaw rate, C_{nr} is the Yaw rate of Damping derivatives,
Roll rate, C_{lp} is the Yaw rate of Damping derivatives,
Yaw rate, C_{lr} is the Yaw rate of Damping derivatives.

3.2 Elevator Deflection:

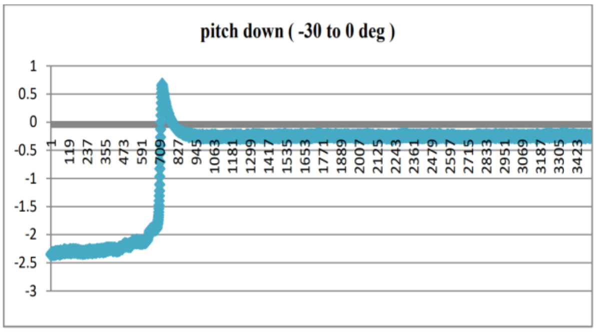
The elevator is deflected +30deg upward and -30 deg downward from the equilibrium using the servo the pitch up rate of the aircraft will be measured and so the pitch down rate.

3.3 Pitch Up and Down:

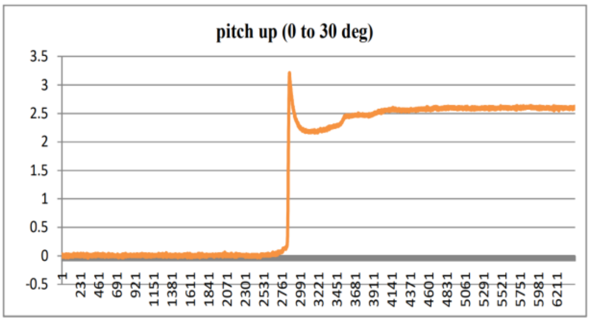
In these graphs, the time is taken on the X axis in milliseconds, and pitch rate is taken on the Y axis in degree/sec.



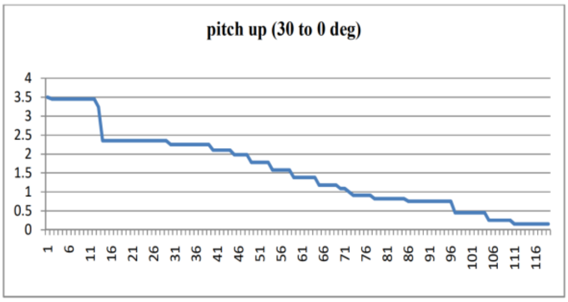
Graph. (1). Pitch Down 1



Graph. (2). Pitch Down 2



Graph. (3). Pitch Up 1

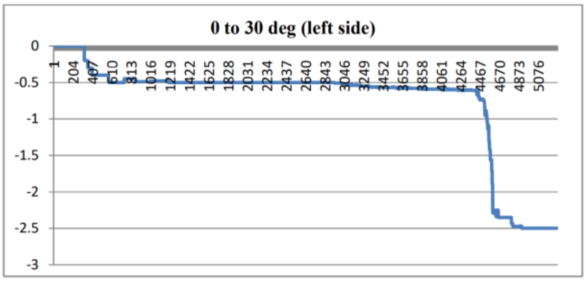


Graph. (4). Pitch Up 2

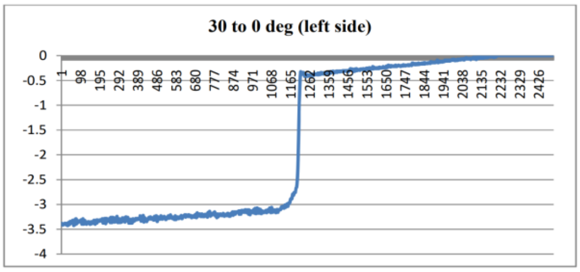
3.3 Rudder Deflection:

The rudder is deflected +30deg left and -30 deg right from the equilibrium using the servo to measure the yaw rates of the aircraft.

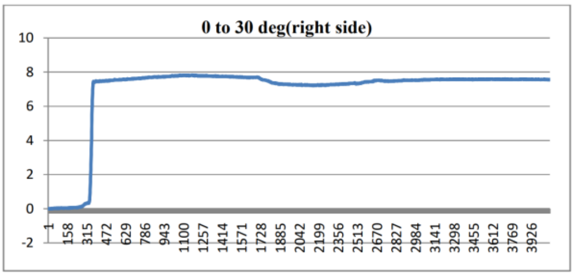
In these graphs, the time is taken on the X axis in milliseconds, and yaw rate is taken on the Y axis in degree/sec.



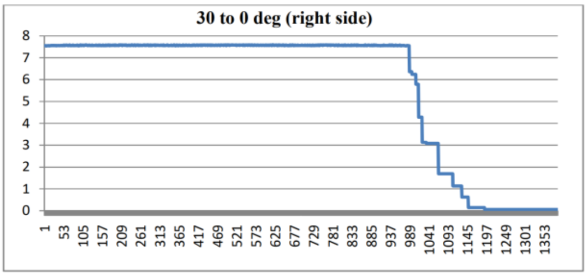
Graph. (5). Yaw 1



Graph. (6). Yaw 2



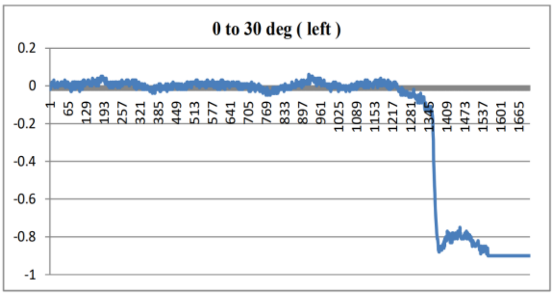
Graph. (7). Yaw 3



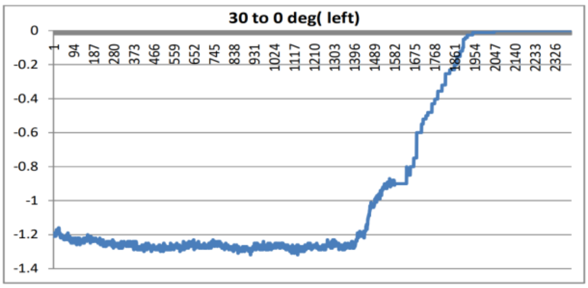
Graph. (8). Yaw 4

3.4 Aileron Deflection:

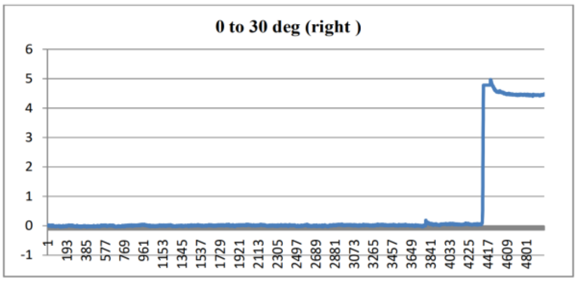
The aileron is deflected +30deg up and -30 deg down from the equilibrium using the servo to measure the roll rates of the aircraft. In these graphs, the time is taken on the X axis in milliseconds, and roll rate is taken on the Y axis in degree/sec.



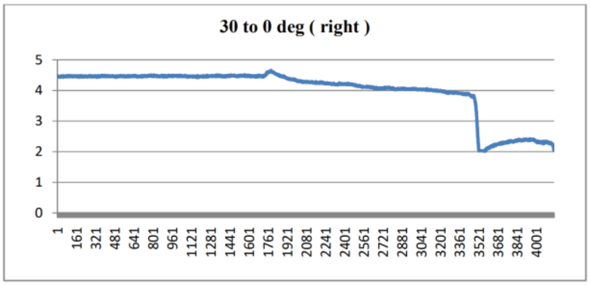
Graph. (9). Roll 1



Graph. (10). Roll 2



Graph. (11). Roll 3



Graph. (12). Roll 4

A wind tunnel balance is a structurally elastic device that measures the aerodynamic load applied to a model during a wind tunnel test. Our Subsonic Wind Tunnel we are keep the prototype is also supported by a wind tunnel balance. The resolution of the entire aerodynamic load into a number of components is one of the key duties of the balance (generally between three and six). There are several different types of wind tunnel balances, each of which is ideal for a certain set of situations. The type of balance is determined by the location in which it is installed. An internal balance is one that is located inside a model, whereas an external balance is one that is located outside of a model or a wind tunnel test section. The focus of this paper was on the internal three-component balance and its calibration.

Conclusion

The control surfaces for an unmanned aerial aircraft were constructed, and it is controlled by servos that are interfaced with the microprocessor and Arduino software. The UAV is mounted on a gimballed mount that has been built. The IMU sensor connected to the microcontroller is used to capture the UAV's damping reaction. The responses were compared and presented as graphs. The servos are controlled by the Arduino, which makes it easier to record the measurements with less human errors. If the pitching moment of the UAV is calculated using force balance, the graph's slope is determined and divided to give the UAV's damping derivative, which will be the focus of future research. The optimal aerodynamic parameters, i.e., the genuine values, are difficult to achieve, as the testing revealed. To begin, the semi-empirical analysis could be damaged by structural parameter inaccuracy, the probable displacement of the centre of gravity, and limited and simplifications. When the filter is interrupted by the wind or gust, the variation flying state makes it exceedingly difficult for the filter to properly and quickly recognise the varied characteristics. To account for the wind, many aerodynamic sensors, monitoring angle-of-attack and side-slip angle with low-cost or handmade vanes, will be fitted in the next study or experiment. As a result, the relatively accurate aeroplane model will be employed as a tool in future study for the rapid diverging pure Inertial Navigation System (INS).

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