# ESTIMATION AND ANALYSIS OF PERFORMANCE, STABILITY AND CONTROL FOR UNMANNED AERIAL VEHICLE (UAV) TAMINGSARI USING SEMIEMPIRICAL METHOD

**by**

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AAA | Advanced Aircraft Analysis |
| ac | Aerodynamic center |
| CDI | Course Deviation Indicator |
| cg | Center of Gravity |
| GPS | Global Positioning System |
| HP | Horse Power |
| mac | Mean Aerodynamic Center |
| RC | Remote Controlled |
| UAV | Unmanned Aerial Vehicle |
| USM | Universiti Sains Malaysia |

# LIST OF SYMBOLS

| | |
|---|---|
| $a$ | Speed of sound |
| $A$ | Wing aspect ratio |
| $A_h$ | Horizontal tail aspect ratio |
| $b$ | Wing span |
| $b_h$ | Horizontal tail span |
| $b_v$ | Vertical tail span |
| $b_a$ | Aileron span |
| $b_e$ | Elevator span |
| $b_e$ | Rudder span |
| $\beta$ | Compressible sweep correction factor |
| $c_r$ | Root Chord |
| $c_t$ | Tip Chord |
| $c_e$ | Elevator chord |
| $c_f$ | Flap chord |
| $c_a$ | Aileron chord |
| $\overline{c}$ | Mean geometric chord |
| $\left(C_{L_\alpha}\right)_{at\ M=0}$ | Mach zero lift curve slope |
| $\left(C_{L_{\alpha h}}\right)_{at\ M=0}$ | Mach zero horizontal tail lift curve slope |
| $C_{L_{\alpha w}}$ | Wing lift curve slope |

| | |
|---|---|
| $d_f$ | Fuselage diameter |
| $d_b$ | Equivalent base diameter |
| $i$ | Incidence angle |
| $K$ | Ratio of airfoil lift curve slope to $2\Pi$ |
| $K_h$ | Ratio of horizontal tail airfoil lift curve slope to $2\Pi$ |
| $L_N$ | Nose length |
| $L_f$ | Fuselage length |
| $M$ | Mach number |
| $S$ | Wing area |
| $S_h$ | Horizontal tail area |
| $S_v$ | Vertical tail area |
| $S_{wet}$ | Wetted area |
| $\overline{V}_h$ | Horizontal tail volume coefficient |
| $X_{cg}$ | Distance between center gravity of aircraft and leading edge of wing |
| $\alpha$ | Angle of attack |
| $\eta_h$ | Ratio of horizontal tail to wing dynamic pressure |
| $\Lambda_{c/2}$ | Semi-chord sweep angle |
| $\Lambda_{c/4}$ | Quarter-chord sweep angle |
| $\lambda$ | Taper ratio |
| $t/c$ | Thickness ratio |
| $Y_{i_f}$ | Inboard flap span |

| | |
|---|---|
| $Y_{o_f}$ | Outboard flap span |
| $Y_{i_a}$ | Inboard aileron span |
| $Y_{o_a}$ | Outboard aileron span |
| $Y_{i_e}$ | Inboard elevator span |
| $Y_{o_e}$ | Outboard elevator span |
| $z_{i_r}$ | Inboard rudder span |
| $z_{o_r}$ | Outboard rudder span |

# ANGGARAN DAN ANALISIS PRESTASI, KESTABILAN DAN KAWALAN UNTUK PESAWAT TANPA PEMANDU TAMINGSARI MENGGUNAKAN KAEDAH SEPARUH EMPIRIK

## ABSTRAK

Tesis ini menerangkan tentang anggaran dan analisis prestasi penerbangan, kestabilan dan kawalan khasnya untuk pesawat tanpa pemandu berdasarkan kaedah separuh empirik. Pesawat tanpa pemandu adalah tidak mempunyai juruterbang di dalam kokpit, tetapi ianya terbang secara autonomi ataupun dikawal menggunakan kawalan jarak jauh. Ianya banyak digunakan di banyak negara untuk tujuan seperti pengawasan, penyelidikan atau peperangan berdasarkan keupayaannya melakukan penerbangan secara autonomi. Pesawat tanpa pemandu Tamingsari dipilih sebagai kes penyelidikan ini yang mana pesawat ini merupakan milik Pusat Pengajian Kejuruteraan Aeroangkasa, Universiti Sains Malaysia. Hasil yang diperolehi daripada kaedah separuh empirik telah dibandingkan dengan perisian Advance Aircraft Analysis (AAA) sebagai alat untuk menentukan kesasihan. Pesawat tanpa pemandu Tamingsari telah menunjukkan keputusan yang baik untuk sebahagian besar parameter yang dianalisis. Ini membuktikan bahawa kaedah separuh empirik memberikan ramalan baik untuk menganalisis parameter aerodinamik, prestasi penerbangan, kestabilan dan kawalan untuk pesawat tanpa pemandu Tamingsari yang bergantung kepada geometri pesawat dalam menilai rekabentuk pesawat tanpa pemandu.

# ESTIMATION AND ANALYSIS OF PERFORMANCE, STABILITY AND CONTROL FOR UNMANNED AERIAL VEHICLE (UAV) TAMINGSARI USING SEMI EMPIRICAL METHOD

## ABSTRACT

This thesis gives deep insight on the estimation and analysis of flight performance, stability and control derivatives particularly for unmanned aerial vehicle (UAV), based on semiempirical methods. UAV is airplane that have no human onboard, but rather are flown autonomously or piloted remotely. It is commonly used in many countries to develop tasks such as surveillance, research or combat due to its autonomy of flight. UAV Tamingsari was selected to be a research case, which belong to the School of Aerospace Engineering, Universiti Sains Malaysia. The results obtained from semiempirical methods have been validated by Advance Aircraft Analysis (AAA) computational software as a tool to check the validity. The validation results of UAV Tamingsari have shown good agreement for most of the parameters analyzed. In this manner, the results showed that the semiempirical methods provide good prediction of aerodynamics, flight performance, stability and control derivatives for UAV Tamingsari due to its approximate geometry inputs, which used to evaluate the UAV configuration.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Unmanned aerial vehicles (UAVs) are airplanes that have no humans on board, but rather are flown autonomously or piloted remotely (Anderson, 2005). UAVs are being used for various potential applications such as environmental monitoring and protection, traffic monitoring, meteorological surveillance, agriculture, aerial target system, airborne surveillance for military land operations, and reconnaissance missions.

In recent years, there has been a significant interest in the research of UAVs as evidenced by the conferences and journal contributions dedicated on quite number of different disciplines ranging from aerodynamics, flight performance, stability and control. The air vehicle design approaches for UAVs follows the principles outlined for manned aircraft (Davies, 2002).

The School of Aerospace Engineering, Universiti Sains Malaysia (USM) has been conducting research and development on UAVs since 2002. Research work to date has produced promising results towards the development of fully autonomous capabilities for unmanned aircraft, and has brought the core autonomous flight control system to an advanced stage of development. An aircraft firstly being developed is the UAV named Tamingsari at USM. Being developed primarily to provide a flight research platform in support of the various research activities, Tamingsari is also used to enhance skills in airframe design and fabrication, flight performance, stability, control, instrumentation, flight control systems, and operational aspects of UAVs. It forms the basis of a technology demonstrator for many aspects of a generic UAV system development and became an integral part of the research.

Current plans are based on the premise that UAVs have the potential to replace manned aircraft in a variety of missions. The advantage of UAVs over manned aircraft is their cost which is only a small fraction of the cost of a manned airplane. Thus they have become an integral part of modern warfare since many missions such as electronic deception, visual identification, laser designation of targets and bomb damage assessment deep in the enemy territory can be performed without endangering any lives or risking any expensive aircraft. They can be launched from practically any type of platform making them ideal for use in the Navy. They are also usually very hard to be detected with radar or infrared systems due to their small size, composite materials and low noise and speed. UAVs are also not limited by the pilot “g” tolerance or fatigue.

The Control System Lab led by Dipl. Ing. Endri Rachman has identify long-term research opportunities for supporting the development of technologies for UAVs at USM. The objectives of the research and development of UAVs were to identify technological developments that would improve the performance and reliability of next generation UAVs at lower cost and to recommend areas of fundamental research in structures, design and autonomous system.

## 1.2 Problem Statement

UAVs are finally and rapidly coming into their own as major tactical and strategic systems on the modern battlefield and academic applications. UAVs share inherent characteristics with manned aircraft but the only main difference is the handling capability. Therefore, this research is to develop the estimation framework for aerodynamics, performance, stability and control specific for unmanned aircraft using semiempirical methods then to compare and prove the analytical results with established software which is Advanced Aircraft Analysis (AAA).

This research will provides the School of Aerospace Engineering, Universiti Sains Malaysia a foundation or platform for future development of UAV capability. Prior to this research, there is no well documentation existed at USM which focus on analysis of aerodynamics, flight performance, stability and control derivatives of UAV especially using semiempirical methods.

## 1.3 Research Objectives

The main objective of this research is to analyse to important parameter of aircraft flight mechanics as it applies to UAVs as well as to provide a proper procedure to estimate the flight performance, stability and control derivatives that applicable in UAV design and analysis process. Basically, the objective can be broken down into two sub-objectives which will be the thoroughly covered in this thesis.

- To develop the procedure of estimation and analysis of performance, stability and control derivatives of UAV Tamingsari using semiempirical approach.
- To compare the analytical value with AAA.

## 1.4 Methodology

Methodology differed for each objective. The estimation and analysis of performance, stability and control of UAV extensively relied upon the UAV configuration. Physical measurements of the UAV were performed in the Flight

Mechanics and Control Laboratory. The method used to analyse the aerodynamics, performance, stability and control coefficients will be considered to achive the objective.

One objective of this study was to create a procedure for UAV to quickly and with relative ease predict the aerodynamics, performance, stability and control of new designs, preferably, while still in the design stage and also after manufacture. To accomplish this goal, predictive methods presented by Roskam (1990) were used to analyse of the UAV of interest. Although the methods presented in these textbooks are intended for large airplanes, it was found that with a few modifications, they can be applied quite well to small UAVs in the subsonic regime.

The performance, stability and control estimation and analysis of UAV presented in this research associated mostly in analytical approach and also a graphical approach. These two approaches complement each other. The graphical approach is the process of communicating visually using graph to present a clear picture of how various characteristics vary over a range of, parameters. In contrast, the analytical approach, is mainly dealing with equations. For these reasons, combination of both approaches seems to be a good approval.

## 1.5 Thesis Outline

This thesis is arranged in accordance to the objectives and approach as mentioned above. Chapter 2 provides a literature review of related subject. Here, the development on previous research and past knowledge will be explained. The topic discussed include calculation techniques and proposed research methodology.

Chapter 3 gives description of UAV Tamingsari configuration with figures of wing, horizontal tail, vertical tail and fuselage is showed with drawing and dimensions.

Chapter 4 discusses the methodology to calculate of aerodynamics, performance and stability and control derivatives. The method will be disccused in more detailed.

Chapter 5 provides the result of the parameter based on methodology in Chapter 4. This includes a reasonable validation to support the results. The thesis closed with conclusion and contribution of the overall research in Chapter 6. There are also recommendations for the improvement for further research.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Today’s UAVs are the result of an evolution in the analysis that compose the vehicle and the processes used in its design and development. The analysis includes aerodynamics, flight performance, stability and control. In each of these areas as they apply to the small UAVs are discussed in the subsequent chapters. This thesis describes a research in the estimation and analysis of unmanned aerial vehicle (UAV) specific into flight performance, stability and control. Specifically, topics include the flight performance prediction, stability and control estimation. The results of study case UAV is discussed and validating with an established tool which is Advanced Aircraft Analysis (AAA) by DARcorporation.

All UAV must be analysed to meet the standard requirements in order to be certified for flight. It is essential for researcher to evaluate the flight performance, stability and control authority of UAV concepts early in the conceptual design phase or existing aircraft. Normally the researcher should consider numerous possible methods depends on the availability data before the flight performance, stability and control can be estimated. In this report a methodology and procedure for estimate and analysis of existing UAV configurations in that particular flight conditions is established. First, the flight conditions has to be considered have to be select. Next, to examine the UAV configurations and the process of estimating stability and control derivatives and flight performance.

Then the results from semiempirical methods of aerodynamics, performance, stability and control derivatives based on geometric data to be compare with AAA. As an educational document, both the report and the software will be continually refined. The intent is not be encyclopedic, or to replace the semiempirical approach. Rather, the intent is to develop well documentation procedure of the analysis of performance, stability and control of UAV. This should provide a much better starting point for more detailed work in modeling and simulation, design of control laws and autonomous systems.

## 2.2 Techniques and Approaches

A number of methods are used to evaluate the aerodynamic, performance, stability and control derivatives. From aerodynamic data, the flight performance, stability and control can be solved. The degree of confidence associated with the estimation is dependent on the quality of the aerodynamic source material and the method of evaluation used.

### 2.2.1 Calculation Techniques

Three classes of aerodynamic calculation techniques are: (a) analytical, (b) semiempirical and empirical, and (c) numerical. As a consequence, it is possible to categorise existing calculation methods into the following distinct classes, see Table 2.1

Table 2.1 Calculation Techniques for Configuration Aerodynamic Analyses

| **Analytical** | **Semiempirical/Empirical** | **Numerical** |
|---|---|---|
| Lifting Line Theory | RAE Standard Method | Vortex Lattice Method |
| Swept-Wing Theory | Hoerner | Panel Method |

| | | |
|---|---|---|
| Swept Lifting Line Theory | DATCOM | Finite Difference Method (CFD) |
| Low Aspect Ratio Wing Theory | ESDU | Finite Element Method (CFD) |
| Loading Function Method | Schemenski | Finite Volume Method (CFD) |
| Modified Lifting Line Method | Missile DATCOM | Spectral Method (CFD) |

#### 2.2.1(a) Analytical

Numerous analytical theories have been developed since the beginning of manned flight, see Table 2.1. Those method range from the most simple to the most complex with the aim theoretically analyse two and three dimensional lifting systems. However, the solutions to the configuration aerodynamics problem are predominantly limited to imcompressible, inviscid fluids. Classical analytical theories are still used to estimate of the forces and moments involved. Those theories are primarily employed , to identify the influence of gross geometric parameters used in the analytical formulations. Overall, the strength of analytical theory is the ability to gain an insight on the physical role of key parameters. Although analytical methods are based on physical reasoning, the modeling is restricted in practice to specific geometries and operational applications.

#### 2.2.1(b) Empirical and Semiempirical

The difficult balance between model complexity, calculation speed, and calculation accuracy has been classically satisfied with the use of empirical (database) methods and semiempirical (engineering) aerodynamic methods. Empirical knowledge is based on practical experience and observation rather than theories and the semiempirical methods means that the parameters used in the correlations were reasonable parameters based on the physics of the situation. In the development of semiempirical methods, basic aerodynamic theory is used to make a first order estimate of the lift and drag and to define reasonable aerodynamic parameters to be used in the correlations. Then empirical corrections are made to the theory to produce good agreement with wind tunnel and flight test data. Clearly, empirical and semiempirical aerodynamic estimation methods like Datcom and ESDU (Engineering Sciences Data) data sheet are restricted to conventional configurations only. This methods do not function outside their underlying database especially for unconventional configuration.

#### 2.2.1(c) Numerical

Numerical estimation methods comprise linear methods like the vortex lattice and panel method families, and CFD (computational Fluid Dynamics) techniques, see Table 2.1. CFD methods require the construction of a grid to fill the flow field volume of interest, resulting in a large number of mesh points. This consequently leads to a very large system of equations, posing particular demands on computational resources

Linear numerical estimation methods are most suitable for conceptual analysis work. Vortex lattice methods (VLM) study the mean geometric surface and panel methods study the geometric surface. Both methods circumvent the modeling task of the geometric volume, thereby avoiding much of the CFD typical pre-processing complexity. However, linear estimation techniques do not estimate effects like boundary layer and wake roll up. They do provide reasonable estimates of the inviscid aerodynamics, including drag, for a large class of airplane geometries in subsonic.

### 2.2.2 Wind Tunnel Measurement

The classical wind tunnel test is one in which a reduced scale model of the aircraft is attached to a balance and the six components of force and moment are measured for various combinations of wind velocity, incidence angle, sideslip angle and control surface angle. The essential feature of such tests is that the conditions are static when the measurements are made. Provided the experiments are carefully designed and executed wind tunnel tests can give good estimates of the force-velocity abd moment-velocity derivatives in particular. Scale effects can give rise accuracy problems, especially when difficult full scale flight conditions are simulated and although some derivatives can be estimated with good accuracy it may be very difficult to devise experiments to measure other derivatives adequately. However, despite the limitations of the experimental methods, measurements are made for real aerodynamic flow conditions and in principle it is possible to obtain derivative estimates of greater fidelity than is likely by analytical, semiempirical/empirical and numerical.

### 2.2.3 Flight Test Measurement

The estimation of aerodynamic derivatives from flight test measurements is an established and well developed experimental process. However, derivative estimates are usually obtained indirectly since it is not possible to measure the aerodynamic components of force and moment acting on the airframe directly. Also, since the aircraft has six degrees of freedom it is not always possible to perturb the single motion variable of interest without perturbing some, or all, of the others as well. However, as in wind tunnel testing, some derivatives are easily estimated from flight test experiment with a good degree of confidence, whereas others can be difficult to estimate.

Today parameter identification techniques are commonly used in which measurements are made following the deliberate excitation of multi-variable dynamic conditions. Complex multi-variable response analysis then follows from which it is possible to derive a complete estimate of the mathematical model of the aircraft corresponding with the flight condition at which the measurements were made. Parameter identification is an analytical process in which full use is made of state space computational tools in order to estimate the aircraft state description that best matches the input-output response measured in flight. It is essentially a multi-variable curve fitting procedure and the computational output is the coefficients in the aircraft state equation from which estimates of the aerodynamic stability and control derivatives may be obtained.

The disadvantages of parameter identification methods includes the requirement for substantial computational and the essential need for recorded flight data of the very highest quality. Despite these constraints, the process is now used routinely by many of the leading flight test organisations. Given adequate resources the advantages of parameter identification methods are significant. All of the aerodynamic stability and control derivatives can be estimated in one pass and the dynamic conditions to which they relate do not necessarily have to be linear. For example, it is now routinely possible to identify aircraft models in extreme manoeuvring conditions such as the stall, the spin at very angles of attack when the aerodynamics are substantially non-linear. It is interesting to note that the method can also be used for estimating aerodynamic derivatives from dynamic wind tunnel experiments.

### 2.2.4 Advanced Aircraft Analysis (AAA)

Advanced Aircraft Analysis (AAA) is the industry standard aircraft design, stability, and control analysis software. AAA is installed in over 45 countries and is used by major aeronautical engineering universities, aircraft manufacturers, and military organizations worldwide.

Advanced Aircraft Analysis provides a powerful framework to support the iterative and non-unique process of aircraft preliminary design. The software consists of ten application modules, a detailed help system, environment setup and project handling tools. Appendix A shows a few snapshots of the program. Advanced Aircraft Analysis uses both British and S.I. units.

Advanced Aircraft Analysis can be used for small (civil), UAV, military and transport airplanes. The program is designed to assist in the design learning process while reserving for the user the individual creative judgment which is essential to the process of airplane design.

Advanced Aircraft Analysis applies to most fixed wing configurations (civil and military aircraft) and allows design engineers to rapidly evolve an airplane configuration from weight sizing through detailed performance calculations and cost estimations. All applicable performance and flying quality regulations are available in the AAA program.

## 2.3 Methodology Selection

To estimate and analysis the performance, stability and control of UAV Tamingsari, we need to select the suitable approach. The estimation can be determined either by analytical, semiempirical, computational fluid dynamics (CFD), or experimental methods. Several empirical and semiempirical methods have been developed over the years for evaluating the aerodynamics, performance, stability and control derivatives of aircraft configurations of practical interest. Semiempirical methods from Roskam (1990) is one of the most widely used sources for estimating aerodynamics, performance, stability and control derivatives for conventional aircraft. It is a comprehensive compilation of all the available engineering methods for obtaining the flight mechanics characteristics of aircraft.

On the other hand, the semiempirical or engineering methods provide quick and cost effective estimates of the aerodynamics, flight performance, static and dynamic stability derivatives , which can be readily used for assessing the vehicle flyablity. Also, the predictions based on semiempirical methods can be used in the design of flight control and guidance systems. The only disadvantage is that such predictions are less accurate compared to the CFD, wind tunnel and flight test data. However, this type of information is very useful and quickly evaluate configuration for their suitability in design stages and also developing the modeling and simulation.

In this thesis, the semiempirical methods proposed by Roskam (1990) is going to be implemented suitable for evaluating the flight mechanics characteristics. Panel method from Drela (2000) is used to determine airfoil characteristics and aerodynamics. Drela (2000) stated that the XFOIL software is helpful to understand the basic aerodynamic concepts underlying the flight performance, stability and control. The results from semiempirical method from Roskam (1990) will be compared with fast software calculation of Advanced Aircraft Analysis (AAA).

## 2.4 Summary of Reviews

There are currently is a great deal of interest in the UAV, both in the military and civilian sectors, owing to their potential to perform dangerous, repetitive tasks in remote or hazardous environments. Most of the UAV require a good flying characteristics of performance, stability and control before the UAV can be assumed able to fly and for the development of flight control laws, simulation and autonomous systems. Since there are many literature have shown that the estimation of aerodynamics, performance, stability and control using semiempirical methods are seemed to be useful and important. Furthermore, a literature review reveals there are no specific documents for UAV especially for the estimation of performance, stability and control. A lot of documents applied to only piloted aircraft and the others just informed that the method that the researcher used in his worked without any documents and procedure involved. Literature becomes less available when it comes to UAVs and this problems inspire me to contribute something in the development of flight mechanics area at Malaysia. Few relevant articles discussing the worked done in this area development of UAVs were found.

This part reviewed the existing literature review in the flight performance analysis as well as stability and control. There is a lot of existing literature reviewed by the ealier reviewers. Conference paper from Rachman (2007) discussed the step by step procedure in the design and development of the control laws of UAV Tamingsari. The process starts with calculating data of aerodynamics, stability and control needed for nonlinear simulation. Also stated that in the process determination of aerodynamics, performance, stability and control derivatives have been estimated using the USAF Digital Datcom and the semiempirical formulas from Roskam book. The aerodynamic data, the stability and control derivatives are used as the parameter for the equations of motion describing the motion of the UAV Tamingsari in the air. The design and development of the control laws/algorithms for UAV Tamingsari is not only just designing and simulating the linear control laws, but there are some issues such as getting the UAV data. This issues is important have to be done and solved in order to achieve autonomous.

Rachman *et al.* (2009) studied the aerodynamics, performance, stability and control for UAV Tamingsari using semiempirical method. Semiempirical is used to make a first order estimate of the lift and drag and to define reasonable aerodynamic parameters to be used in the estimation of performance, stability and control.

Sweeten *et al.* (2009) focuses on the flight performance analysis using Roskam approach and AAA. The comparison were made with approach from flight testing methods. Arroyo (2007) wrote a Masters thesis which used computational analysis to study the aerodynamic of an UAV, in order to calibrate the equations of stability and control needed for the programming of their autopilot. Fluent and semiempirical methods are used to calculate the aerodynamic derivatives. This thesis used the measurements of the geometries that can be used in the modeling into a software of design steps to the simulation of the aircrafts. Jodeh (2006), in his masters thesis work, stated the development of autonomous UAV in the platform of modeling, simulating and flight testing. In order to achieve this, in first component of his thesis that the analysis of stability and control based on physical characteristics, which used semiempirical methods.

Conference paper by Tinapp *et al.* (2008), stated that in order to optimize flight control system and the performance of aircraft, a dynamical model of the aircraft is needed that can be obtained by calculating the stability and control derivatives. This paper described the results of aerodynamic modeling of a UAV, using free available calculations tool for aerodynamic analysis and flight mechanics such as XFOIL, AVL (Anthena Vortex Lattice) and Roskam.

Jung *et al.* (2007), this article describes a complete simulation environment which has been developed at Georgia Tech for testing and validating UAV control systems. Here the aerodynamic, stability and control derivatives are obtained from DATCOM and Roskam. Keshmiri *et. al* (2008), describes a modeling and simulation of unmanned aerial vehicle using parameter and system identification. The numerical values of the aerodynamic derivatives are computed using semiempirical methods software to investigate the geometric parameters of the airplane. For comparison a series of flight tests are conducted. The comparison results are used in the development of a new autopilot system for small UAVs.

Bergen *et. al*, (2008), This article describes a correlation of handbook method results with wind tunnel data for a subsonic UAV. The handbook methods are used to size the aircraft and to predict its aerodynamic characteristics and flight performances. For a new twin-boom pusher UAV a systematic comparison of theoretical predictions and wind tunnel test data is performed. It is shown that although performance and stability parameters are generally well predicted important deviations can occur if the specific airplane configuration is not taken into account in a sufficiently accurate manner.

Garcia and Becker (2007) described about the hardware-in-the-loop simulation. This paper stated that the use of a vortex lattice aerodynamic code and manual methods from Roskam for the estimation of stability derivatives and qualitative flight testing for the determination of the final values. Leong *et al.* (2008), wrote a conference paper about the development of a pilot training platform for UAVs using a six degree of freedom nonlinear model with flight test validation. In this paper describes that the semiempirical methods is utilized to compute the aerodynamics, performance, stability and control derivatives, which are used to compose the state space models and after that validate with flight test.

From all the reviews shown that the semiempirical methods played an important role to determine and estimate the aerodyanmics, performance, stability and control derivatives in early stage of design and development and also can be used in the modeling and simulation.

## 2.5 Thesis Contributions

In the section 2.4 the reviewers stated that the important of semiempirical methods for estimating aerodynamics, performance, stability and control in the development of modeling and simulation, design of flight control laws, autopilot and autonomous systems. There are no papers or theses that desribed the procedure in the implementation of semiempirical methods to the UAV. So, to fulfill the need of the case of UAV aerodynamics, performance, stability and control, the development of estimation framework that specific to the UAV need to work out and used UAV Tamingsari as an example in the analysis and estimation.

# CHAPTER 3

# UNMANNED AERIAL VEHICLE (UAV) TAMINGSARI

## 3.1 Intoduction

Tamingsari is a low altitude, short range Unmanned Aerial Vehicle (UAV) which performs aerial surveillance and reconnaissance missions for civil use such as remote sensing, air photography, sampling of plantation topography, and monitoring of traffic and flooding area. After detailed design and manufacturing, the configuration of Tamingsari has following features:

- Dimension: a length of 2.5 m, a wing span of 3 m and the maximum fuselage diameter of 0.3 m.
- Airframe configuration: circular fuselage, straight and non-tapered wing, twin tail booms with elevator on the top of vertical tails.
- Engine mounting: pusher (aft)
- Landing gear: triple, fixed landing gear.
- Material: fiberglass (body, empennage), fiberglass covered balsa-wood (wing)

The propulsion system uses two stroke piston propeller engine of Model Motoren that is equipped with course deviation indicator (CDI) and can produce gross power of 5.2 HP. The Tamingsari equipped with an onboard computer Micropilot that is connected to a flight control unit for autonomous flight. The flight Control System consists of the radio remote control (Transmitter and Receiver), servo motor, push-pull rod control linkage system. The Tamingsari can be operated manually using remote controlled (RC) or autonomous and monitored on ground with portable personal computer. Beside that the onboard computer is connected to a sensor system for measuring the attitude, rate, airspeed and altitude of the Tamingsari and an navigation system (GPS) for position determination. Wiring system has been put into Tamingsari and consists of two unit of battery and voltage regulator to operate the UAV system. A battery of twelve volt is used for autopilot, navigation GPS, wireless modem, servo motor, RC-control system, sensor system and payload camera and other battery of 6 volt for engine CDI.

## 3.2 UAV Configuration

### 3.2.1 Three View Drawing of UAV Tamingsari

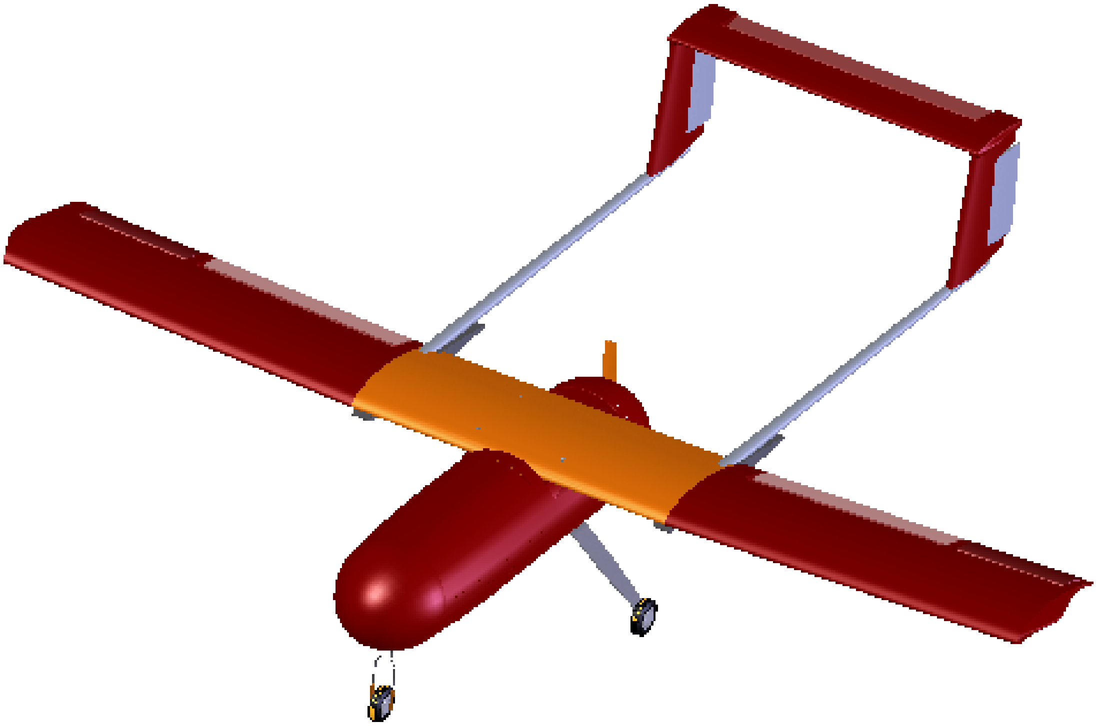

Figure 3.1 Three Dimensional View of UAV Tamingsari

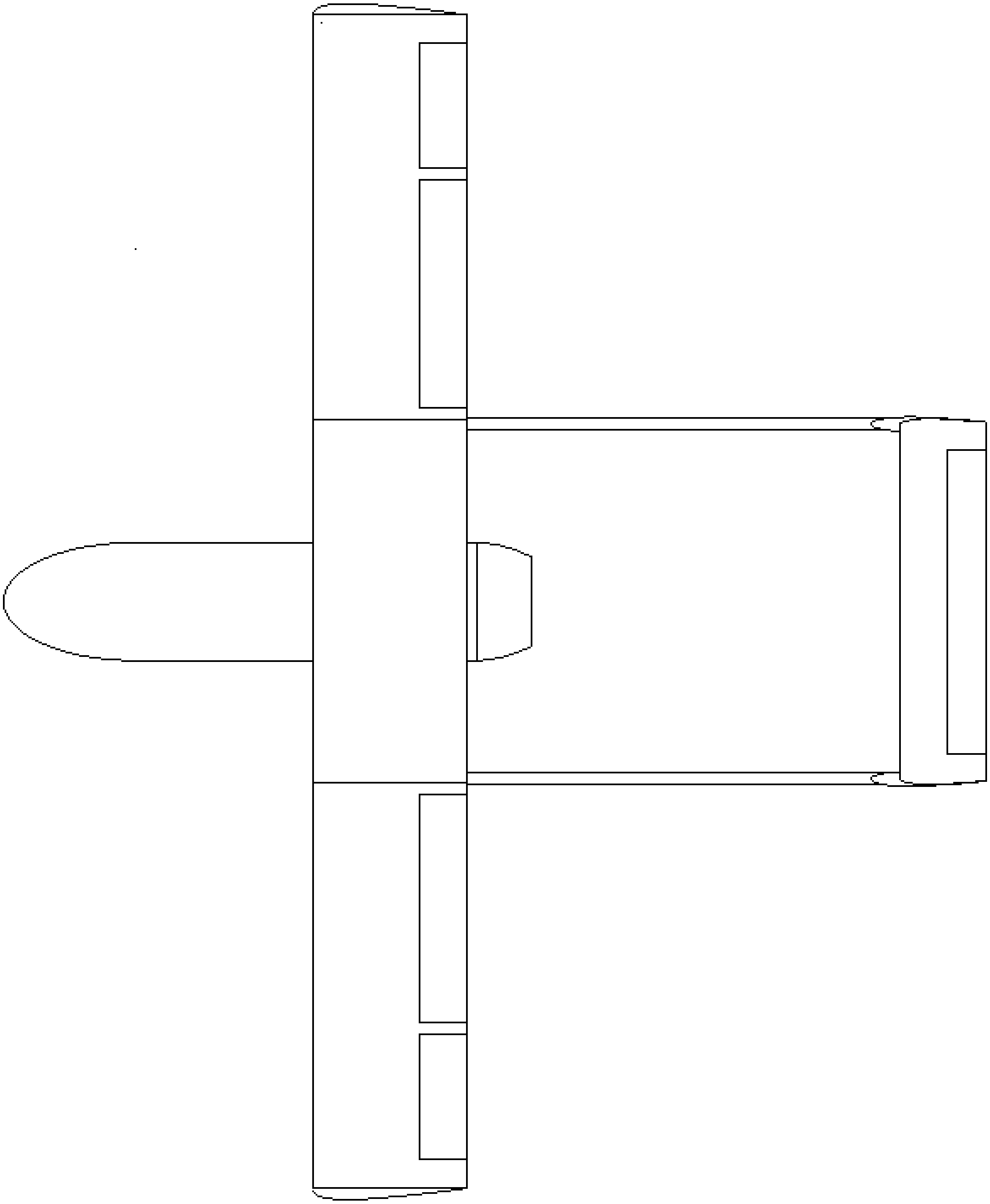

Figure 3.2 Top View of UAV Tamingsari

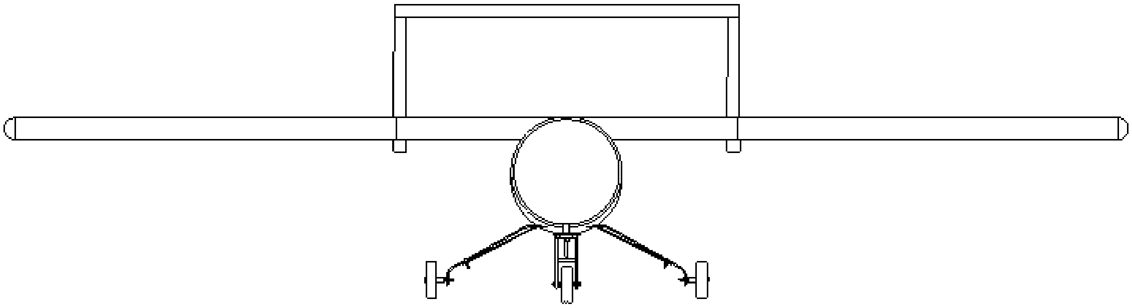

Figure 3.3 Front View of UAV Tamingsari

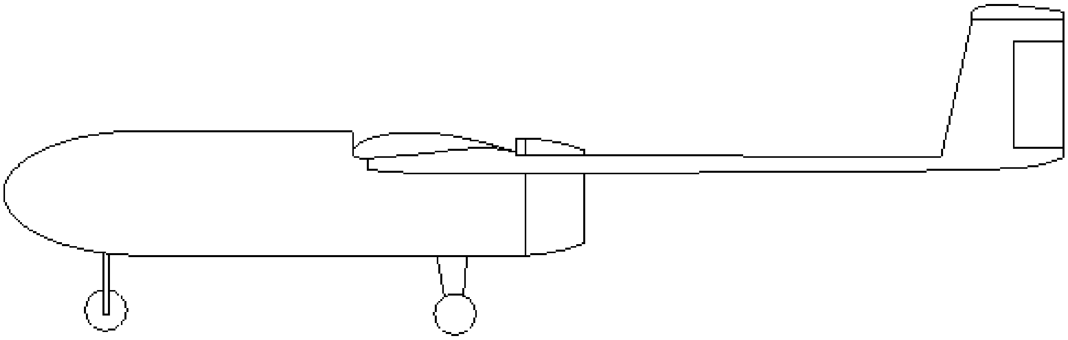

Figure 3.4 Side View of UAV Tamingsari

### 3.2.2 Wing Geometry

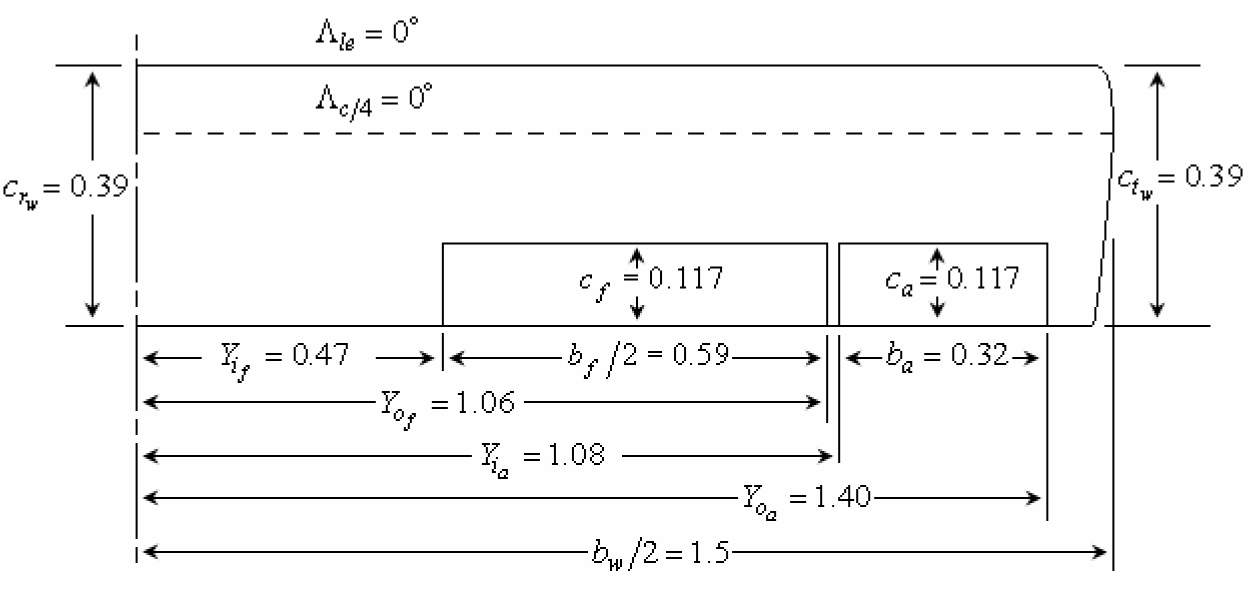

Figure 3.5 Definition of Wing, Flap and Aileron Parameters (unit in meter)

Table 3.1 Description Parameters of Wing, Flap and Aileron

| Parameter | Value |
|---|---|
| Planform Shape | Rectangular wing |
| Wing Span, $b$ | 3 m |
| Airfoil | Wortmann FX 63-137 |
| Thickness ratio, $t/c$ | 0.137 |
| Wing Planform Area, $S$ | 1.17 m$^2$ |
| Root Chord, $c_r$ | 0.39 m |
| Tip Chord, $c_t$ | 0.39 m |
| Mean Aerodynamic Chord, $\overline{c}$ | 0.39 m |
| Leading Edge Sweep | $0^\circ$ deg |
| Half chord sweep, $\Lambda_{c/2}$ | $0^\circ$ deg |
| Quarter chord sweep, $\Lambda_{c/4}$ | $0^\circ$ deg |
| Dihedral Angle | $0^\circ$ deg |
| Twist Angle | $0^\circ$ deg |
| Incidence Angle | $-2^\circ$ deg |
| Taper Ratio | 1 |
| Aspect Ratio | 7.6923 |

### 3.2.3 Fuselage Geometry

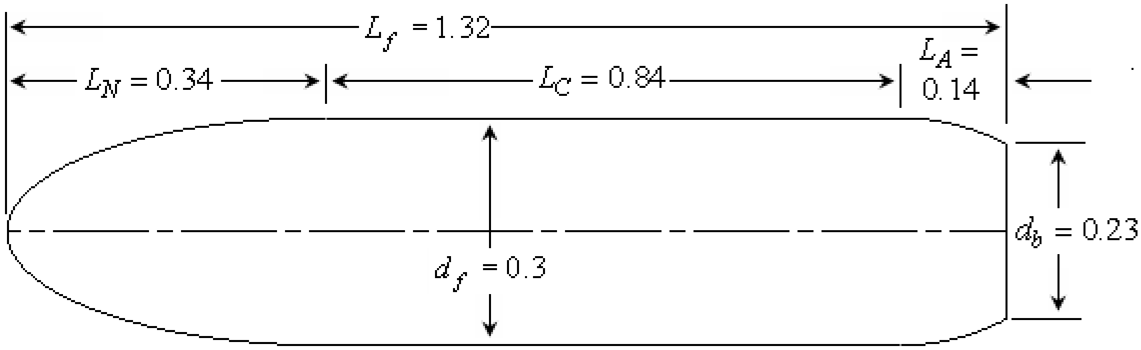

Figure 3.6 Definition of Fuselage Parameters (unit in meter)

### 3.2.4 Horizontal Tail Geometry

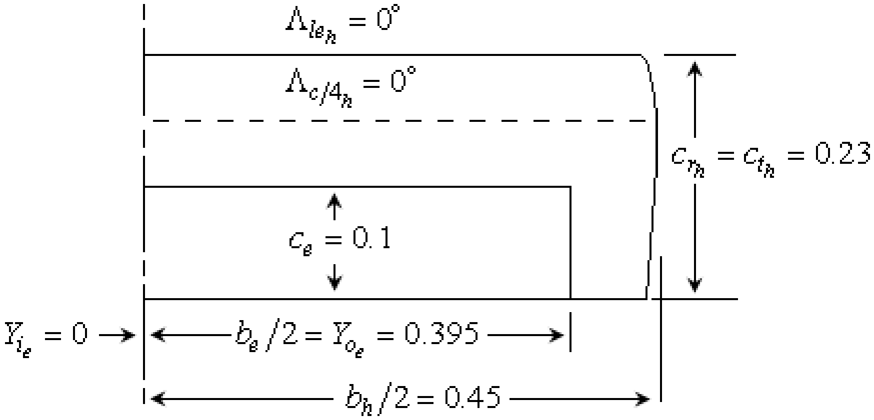

Figure 3.7 Definition of Horizontal Tail and Elevator Parameters (unit in meter)

Table 3.2 Description Parameters of Horizontal Tail and Elevator

| Parameter | Value |
|---|---|
| Planform Shape | Rectangular |
| Span | 0.9 m |
| Airfoil | NACA 0012 |
| Area | 0.207 m$^2$ |
| Root Chord | 0.23 m |
| Tip Chord | 0.23 m |
| Mean Aerodynamic Chord | 0.23 m |