UNIVERSITI PUTRA MALAYSIA

# STABILITY AND CONTROL ASSESSMENT OF AN AERIAL TARGET DRONE BASED ON A SCALE MODEL OF A-4 SKYHAWK JET FIGHTER

ABU ZAID BIN BAKAR

# STABILITY AND CONTROL ASSESSMENT OF AN AERIAL TARGET DRONE BASED ON A SCALE MODEL OF A-4 SKYHAWK JET FIGHTER

**ABU ZAID BIN BAKAR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Master of Science**

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## DEDICATION

I praised to Allah the Almighty, given me the knowledge, effort and strength to complete this Master Degree. My respected mother, Madam Rakhiya Bee Binti Junoos, beloved wife Wan Noramelia Merican Binti Noorsa Merican, daughter, Nur Farhanah Zulaikha and new baby boy, Muhammad Faris.

## ABSTRACT

**Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science**

**STABILITY AND CONTROL ASSESSMENT OF AN AERIAL TARGET DRONE BASED ON A SCALE MODEL OF A-4 SKYHAWK JET FIGHTER**

**By**

**ABU ZAID BIN BAKAR**

**May 2009**

**Chairman : Abd Rahim Bin Abu Talib, Ph.D.**

**Faculty : Faculty of Engineering**

A-4 Skyhawk is a jetfighter aircraft which was bought by our Royal Malaysia Air Force (RMAF) back in the year 1980s. The study is to evaluate the stability and control aspects of the design of A-4 Skyhawk as a target drone with a scale of one third. The condition of the studies involve the longitudinal and lateral controls of the open loop derivatives at the sea level and 10,000 feet altitude, for ranges of Mach number of 0.2, 0.3, 0.4, 0.5 and 0.6. Hence, the closed loop derivatives shall be designed to cater for the unsatisfactory parameters.

With the usage of stability software such as the United State Air Force Stability and Control DATCOM (USAF DATCOM), analysis softwares such as MATLAB and CATIA, the method of design concept shall be more viable in order to produce a stable design. The USAF DATCOM software is used to generate the static and dynamic aerodynamic derivatives of the given aircraft. MATLAB is mathematical software used

to perform high speed and massive calculations. MATLAB is used to obtain the transfer function of the aircraft equation of motion, to perform stability analysis and to plot the stability related graphs. The CATIA software is used to develop the full scale and scale size model of the A-4 Skyhawk jetfighter. From this software the scale model dimension, estimated weight and second moment of inertia is obtained. Thus, combination of all the software and calculation, the output of the study shall be able to meet the objectives of the study.

It was found that, for the open loop derivatives of the longitudinal motion, the flying qualities for both short period and phugoid modes felt in the Level 2 category. As for the lateral motion, the flying qualities of the Dutch roll, spiral and roll modes felt in the Level 1 category as described by the Cooper-Harper scale.

However, the critical scenario for the longitudinal and lateral for both the sea level and 10,000 feet altitude occurred at the speed of Mach number 0.2, where it had the most oscillatory conditions and the least settle for steady state condition. This may due to the less effectiveness of the delta wing at low speed flying condition.

**ABSTRAK**

**Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains**

**PENILAIAN DALAM KESTABILAN DAN MENGAWAL KAPAL TERBANG SASARAN BERDASARKAN DARIPADA SKALA MODEL JET PEJUANG A-4 SKYHAWK**

**Oleh**

**ABU ZAID BIN BAKAR**

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A-4 Skyhawk merupakan pesawat jetpejuang yang telah dibeli oleh Tentera Udara Di Raja Malaysia dalam tahun 1980an. Kajian ini dibuat adalah untuk menyelidiki tahap stabiliti rekabentuk pesawat A-4 Skyhawk sebagai pesawat sasaran dengan dikecilkan sebanyak 1/3 daripada bentuk asal. Kajian ini meliputi keadaan pesawat dari segi menegak dan juga melintang di dalam situasi kawalan terbuka, pada ketinggian paras laut dan ketinggian 10,000 kaki dari paras laut, dan merangkumi kelajuan nombor Mach 0.2, 0.3, 0.4, 0.5 dan 0.6. Setelah itu, kawalan tertutup akan direka untuk mengatasi situasi yang kritikal yang dihadapi oleh pesawat ini.

Dengan menggunakan peralatan sistem komputer stabiliti seperti United State Air Force Stability and Control DATCOM (USAF DATCOM), peralatan analisis seperti MATLAB dan peralatan komputer rekacipta seperti CATIA, cara-cara untuk mendapatkan konsep rekacipta pesawat adalah didapati lebih berkesan bagi

merekabentuk sebuah pesawat yang stabil. Sistem USAF DATCOM digunakan untuk mendapatkan bacaan aerodinamik bagi keadaan statik dan dinamik untuk sesebuah pesawat itu. MATLAB adalah penganalisa matematik bagi tujuan pengiraan yang pantas dan banyak. MATLAB digunakan bagi tujuan mendapatkan fungsi pengubahan bagi persamaan bagi pergerakan pesawat, untuk menganalisa stabiliti dan untuk melakarkan graf stabiliti yang berkenaan. Sistem CATIA pula digunakan untuk melakarkan model skala penuh dan skala tertentu bagi pesawat jetpejuang A-4 Skyhawk. Melalui CATIA, dimensi model berskala, anggaran berat pesawat serta inersia tahap kedua dapat diperolehi. Oleh yang demikian, dengan penggabuhan sistem kompoter dan pengiraan yang dinyatakan, hasilnya didapati boleh memenuhi matlamat penyelidikan ini.

Hasil kajian didapati bahawa, bagi situasi kawalan terbuka untuk sudut melintang, kualiti penerbangan bagi kedua-dua jangka pendek dan jangka panjang adalah di dalam kategori peringkat kedua. Manakala untuk sudut membujur pula, kesemua kualiti penerbangan adalah di dalam kategori peringkat pertama mengikut skala Cooper-Harper.

Walaubagaimanapun, situasi yang kritikal yang dihadapi oleh pesawat ini bagi posisi melintang dan membujur untuk ketinggian paras laut dan 10,000 kaki dari paras laut adalah pada kelajuan 0.2 nombor Mach, dimana ia mempunyai tahap pergerakan yang berulang-ulang serta ia juga mengambil masa yang paling lama untuk stabil. Ini mungkin berpunca daripada kurang efektifnya sayap berbentuk delta bagi penerbangan pada kelajuan yang rendah.

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I certify that a Thesis Examination Committee has met on 17 September 2009 to conduct the final examination of Abu Zaid Bin Bakar on his thesis entitled "Stability and Control Assessment of an Aerial Target Drone Based on Scaled Model of A-4 Skyhawk Jet Fighter" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Date: 14 January 2010

**DECLARATION**

I declare that the thesis is based on my original work except for quotations and citations which have been dully acknowledged. I also declare that it has not been previously or is not concurrently, submitted for any other degree at UPM or other institutions.

**ABU ZAID BIN BAKAR**

11 February 2010

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| $M_q$ | Pitching moment due to pitch rate | 24 |
| $M_w$ | Pitching moment due to velocity in z-direction | 24 |
| $M_{\delta_e}$ | Pitching moment due to change in elevator | 24 |
| $M_{\dot{w}}$ | Pitching moment due to change in velocity in z-direction | 24 |
| $N_\beta$ | Yawing moment due to sideslip angle | 25 |
| $L_\beta$ | Rolling moment due to sideslip angle | 25 |
| $N_p$ | Yawing moment due to roll rate | 25 |
| $L_p$ | Rolling moment due to roll rate | 25 |
| $N_r$ | Yawing moment due to yaw rate | 25 |
| $L_r$ | Rolling moment due to yaw rate | 25 |
| $N_{\delta_a}$ | Yawing moment due to change in aileron deflection | 25 |
| $N_{\delta_r}$ | Yawing moment due to change in rudder deflection | 25 |
| $L_{\delta_a}$ | Rolling moment due to change in aileron deflection | 25 |
| $L_{\delta_r}$ | Rolling moment due to change in rudder deflection | 25 |
| $I_x$ | Second moment of inertia in x-direction | 25 |
| $I_y$ | Second moment of inertia in y-direction | 25 |
| $I_z$ | Second moment of inertia in z-direction | 25 |

| | | |
|---|---|---|
| $\Sigma F$ | Summation of all external forces acting on a body | 29 |
| $\frac{d}{dt}(mV)$ | Time rate of change of the momentum of the body | 29 |
| $\Sigma M$ | Summation of the external moment acting on the body | 29 |
| $\frac{dH}{dt}$ | Time rate of change of the moment of momentum | 29 |
| $X_u$ | Axial force due to velocity component in x-direction | 32 |
| $X_w$ | Axial force due to velocity component in z-direction | 32 |
| g | Gravitational acceleration | 32 |
| $Z_u$ | Normal force due to velocity component in x-direction | 32 |
| $Z_w$ | Normal force due to velocity component in z-direction | 32 |
| $u_0$ | Reference velocity component in x-direction | 32 |
| $\Delta\dot{x}$ | Rate of change in velocity component in x-direction | 32 |
| $\Delta\dot{w}$ | Rate of change in velocity component in z-direction | 32 |
| $\Delta\dot{\theta}$ | Rate of change in pitching angle | 32 |
| $\Delta\dot{q}$ | Rate of change in pitch with respect to time | 32 |
| $X_{\delta_e}$ | Axial force due to change in elevator angle | 32 |
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| $Z_{\delta_e}$ | Normal force due to change in elevator angle | 32 |
| $Z_{\delta_T}$ | Normal force due to change in throttle setting | 32 |
| $\Delta$ | Increment of parameter | 32 |
| $\delta_e$ | Elevator angle | 32 |

| | | |
|---|---|---|
| $\delta_T$ | Throttle setting | 32 |
| $\eta$ | Control vector | 32 |
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| $\beta$ | Side slip angle | 35 |
| $p$ | Roll rate | 35 |
| $r$ | Yaw rate | 35 |
| $\phi$ | Bank angle | 35 |
| $\delta_a$ | Aileron deflection | 35 |
| $\delta_r$ | Rudder deflection | 35 |
| $\zeta$ | Damping ratio | 38 |
| $C_D$ | Drag coefficient | 45 |
| $C_L$ | Lift coefficient | 45 |
| $C_M$ | Coefficient of pitching moment | 45 |
| $C_N$ | Coefficient of yawing moment | 45 |
| $C_A$ | Coefficient of axial force | 45 |
| $C_{L_\alpha}$ | Variation of aircraft lift coefficient with angle of attack | 45 |
| $C_{m_\alpha}$ | Variation of aircraft pitching moment coefficient with angle of attack | 45 |

| | | |
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| $C_{Y_{\beta}}$ | Variation of aircraft side slip force coefficient with roll rate | 45 |
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| $C_{l_{\beta}}$ | Variation of aircraft rolling moment coefficient with side slip angle | 45 |
| $C_{l_q}$ | Variation of aircraft rolling moment coefficient with pitch rate | 45 |
| $C_{M_q}$ | Variation of aircraft pitching moment coefficient with pitch rate | 45 |
| $C_{L_{\alpha}}$ | Variation of aircraft lift coefficient with angle of attack | 45 |
| $C_{m_{\alpha}}$ | Variation of aircraft pitching moment coefficient with angle of attack | 45 |
| $C_{l_p}$ | Variation of aircraft rolling moment coefficient with roll rate | 45 |
| $C_{Y_p}$ | Variation of aircraft side force coefficient with roll rate | 45 |
| $C_{n_p}$ | Variation of aircraft yawing moment coefficient with roll rate | 45 |
| $C_n$ | Coefficient of yawing moment | 45 |
| $C_l$ | Coefficient of rolling moment | 45 |
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| $b$ | Wing span | 58 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Preface

Aircraft design is an intellectual engineering process of creating on paper or on computer a flying machine to meet certain specifications and requirements established by potential users. It is also use to develop new idea and technology (Raymer, 1999).

In Malaysia, aircraft design is still a new field yet to be ventured since it has not been taken seriously. Malaysia has produced two-seater light aircrafts, which are Eagle Aircraft (CTRM, 2007) and MD 3 (Prakash, 2000). These projects were only concerned only on the manufacturing stage, but not the designing stage. In order to improve the design ability in aerospace industry, Malaysian aerospace industries should be involved in designing aircrafts. By doing so, it will expose the local engineers and technicians to the every aspect of the aircraft design.

Most of the modern fighter aircraft designs are shifting from the naturally stable airframe towards sophisticated flight control systems. The advent of highly-augmented flight control systems has decreased the accuracy with which the static and dynamic derivatives must be known in preliminary design. Furthermore, significant errors in the estimation of the static and dynamic derivatives can result in