UNIVERSITI PUTRA MALAYSIA

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF WAU BULAN WING-TAIL CONFIGURATION WITH SELECTED AIRFOIL PROFILE

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By

CATUR SETYAWAN KUSUMOHADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of the Requirement for the Degree of Doctor of Philosophy

September 2011

DEDICATION

This Thesis is Dedicated to my:

My Parents
Bapak & Ibu Soekemi
Ibu Wasithoh Bahran

My wife
Siti Zakiyah

My child
Ibnu Afif Kusumahadi

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Prof. Ir. Shah Nor Basri, PhD

Faculty : Faculty of Engineering

Wau bulan is one of the traditional Malaysia kites. *Wau bulan* consists of two parts which are wing and tail. Its configuration shows possible application as baseline planform of an aircraft. Wau bulan wing tail configuration is indicated as controllable and could meet the stability requirements. It is implied that *wau bulan* can be used as "Sensorcraft UAV configuration" that can meet the requirement of 360^{o} unobstructed radar vision area. In this research, this *wau bulan* planform will be used as baseline of mini UAV configuration.

Wau bulan wing planform shape that is close to elliptical shape, theoretically will have high efficiency factor. However, *wau bulan* has a low aspect ratio wing that causes high induced drag and will generate a low lift over drag ratio. Furthermore, *wau bulan* large tail area and short tail boom can also create significant trim drag. The focus of the research is to investigate the longitudinal aerodynamic

characteristics of wau bulan wing tail configuration. It aims to verify that the wau bulan can fulfill the requirements of surveillance mini UAV.

The research consists of baseline geometry definition, computational analysis and wind tunnel testing of isolated wau bulan wing and wing-tail configuration. Results of analysis would be compared with the assumed ones from initial sizing process.

The baseline geometry was determined based on the initial sizing results, whereby initial sizing is the standard procedure of UAV initial calculation to predict the weight, power loading and wing loading based on surveillance mini UAV performance criteria. Airfoil was applied to create thickness of baseline geometry planform, where Kennedy Marsden Mod airfoil was chosen. It is a thick airfoil and was designed for low Reynolds number flow.

FLUENT software was used as a tool for computational analysis, since it can accommodate 2D and 3D models. The results show the correlation of longitudinal aerodynamic characteristics between 2D airfoil with and without boundary layer mesh, isolated wing and wing tail configuration. The gaps between calculation results were justified by using the validation process. The boundary layer mesh shows significant effect toward aerodynamics calculation.

Wind tunnel testing was conducted at UPM low speed open wind tunnel. This suction type wind tunnel is equipped with external balance to measure the aerodynamic forces and moments. Wind tunnel results show similar value of aerodynamics coefficient especially lift coefficient, between isolated wing and wing

tail configuration. The effect of symmetrical tail cross section was observed at high angle of attack when the tail produces lift.

Despite gaps between the experimental and computational results, the values still can be used to predict longitudinal aerodynamic characteristics of wau bulan wing tail configuration through validation process. The results show that the maximum lift coefficient of wing-tail configuration is close to the 2D airfoil one. Based on this condition, the improvement of wau bulan UAV can be predicted by using the 2D airfoil data.

The analysis results prove that the longitudinal aerodynamic parameters of wau bulan UAV can be achieved. The maximum lift coefficient and lift over drag ratio values from computational and wind tunnel test are higher than the assumed ones during performance sizing. These results give opportunities to improve wau bulan UAV performance because the excess value could compensate additional weight or fuel.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

CIRI-CIRI AERODINAMIK PADA ARAH LONGITUDINAL UNTUK TATARAJAH SAYAP-EKOR DARI PADA WAU BULAN UAV DENGAN MENGGUNAKAN PROFAIL AIRFOIL YANG TERPILIH

oleh

CATUR SETYAWAN KUSUMOHADI

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Wau bulan ialah salah satu layang-layang tradisional Malaysia. Layang-layang Wau bulan terdiri daripada dua bahagian ianya bahagian sayap dan ekor. Konfigurasi ini juga menunjukkan kemungkinan untuk diguna pakai sebagai planform asas pesawat. Konfigurasi ekor sayap mengesahkan bahawa konfigurasi ini boleh dikawal dan dapat memenuhi keperluan kestabilan. Konfigurasi ini juga membuktikan bahawa wau bulan boleh digunakan sebagai konfigurasi daripada “Sensorcraft UAV " yang boleh memenuhi penglihatan radar pada kawasan 360^{o} yang tanpa halangan. Dalam kajian ini, planform wau bulan akan digunakan sebagai asas konfigurasi UAV mini.

Secara teorinya, bentuk planform daripada sayap wau bulan adalah berhampiran dengan bentuk elips yang mempunyai satu faktor efisiensi yang cukup tinggi. Walau bagaimanapun, wau bulan mempunyai aspek rasio sayap yang rendah ianya akan menyebabkan daya heret tinggi dan akan mengkurangkan nilai nisbah daya angkat terhadap daya heret. Tambahan pula, ekor wau bulan yang besar dan paip sambungan ekor yang pendek juga boleh mewujudkan tambahan daya heret trim yang ketara.

Tumpuan penyelidikan ialah untuk menyiasat ciri-ciri aerodinamik ekor konfigurasi sayap wau bulan pada arah longitudinal. Matlamat ini dinyatakan untuk dapat mengesahkan bahawa wau bulan dapat memenuhi persyaratan sebagai mini UAV untuk pengawasan.

Penyelidikan mengandungi takrif geometri asas, analisis komputasi dan ujian terowong angin daripada sayap dan konfigurasi sayap-ekor wau bulan. Kumpulan daripada keputusan analisis akan dibandingkan nilai yang dianggarkan pad proses penentuan saiz awal.

Geometri garis asas dasar tersebut ditentukan berasaskan kepada hasil proses penentuan saiz awal. Penentuan saiz awal ialah prosedur standard daripada pengiraan awal untuk suatu UAV ianya meramalkan berat, loading kuasa dan bebanan sayap yang berdasarkan kepada kriteria prestasi daripada surveillance mini UAV. Aerofoil untuk sayap dipilih semasa takrif geometri asas dilakukan. Airfoil Kennedy Marsden Mod telah dipilih. Ia adalah airfoil yang tebal dan direka bentuk untuk aliran dengan nombor Reynolds yang rendah.

Perisian FLUENT telah diguna sebagai alat bagi analisis komputasi. Perisian ini boleh diguna untuk pengiraan model 2D dan 3D. Keputusan analisis komputasi menunjukkan hubung kait daripada ciri-ciri aerodinamik pada arah longitudinal aerofoil 2D dengan dan tanpa grid boundary layer, sayap dan konfigurasi ekor sayap. Boundary layer mempunyai kesan yang besar ke atas pengiraan aerodinamik.

Ujian terowong angin telah dijalankan di terowong angin terbuka berkelajuan rendah yang berada dekat UPM. Terowong angin jenis sedutan ini dilengkapi dengan external balance untuk mengukur daya dan momen aerodinamik. Keputusan terowong angin menunjukkan bahawa sayap dan konfigurasi ekor sayap mempunyai nilai aerodinamik yang sama terutamanya nilai daya angkat maksima. Kesan daripada ekor simetri ditunjukkan pada sudut serang yang tinggi apabila ekor menghasilkan daya angkat.

Walaupun terdapat perbezaan antara keputusan uji kaji dan komputasi, tetapi dengan menggunakan proses pengesahan, nilai-nilai yang sedia ada boleh diguna untuk meramal ciri-ciri aerodinamik konfigurasi sayap-ekor wau bulan pada arah longitudinal. Keputusan yand diperolehi menunjukkan bahawa daya angkat maksimum konfigurasi sayap-ekor berhampiran dengan daya angkat maksima daripada airfoil 2D. Berdasarkan kenyataan ini, peningkatan prestasi daripada wau bulan UAV boleh diramalkan dengan menggunakan data airfoil 2D.

Keputusan analisis membuktikan bahawa parameter aerodinamik daripada wau bulan UAV pada arah longitudinal boleh dicapai. daya angkat maksimum dan nisbah daya angkat ke atas daya heret daripada proses analisis ialah lebih tinggi daripada yang dianggarkansemasa penentuan saiz awal. Keputusan ini memberikan peluang-peluang untuk peningkatan wau bulan UAV kerana ini nilai yang berlebih ini boleh diguna untuk memberikan tambahan berat atau minyak.

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I certify that a Thesis Examination Committee has met on 22 September 2011 to conduct the final examination of Catur Setyawan Kusumohadi on his thesis entitled "Longitudinal Aerodynamic Characteristics of *Wau Bulan* Wing-Tail Configuration with Selected Airfoil Profile" in accordance with the Universities and University Collegeg 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 Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

CATUR SETYAWAN KUSUMOHADI

Date: 22 September 2011

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