UNIVERSITI PUTRA MALAYSIA

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN AIRCRAFT MODEL WITH AND WITHOUT WINGLET

MD. ALTAB HOSSAIN.

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LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN AIRCRAFT MODEL WITH AND WITHOUT WINGLET

By

MD. ALTAB HOSSAIN

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

October 2005

DEDICATION

Dedicate this thesis

To his teachers;

To his parents Md. Golbar Hossain and Mrs. Aleya Khatoon

And

To the memory of his Late Grandfather who had devoted his love and guiding of the family

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

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN AIRCRAFT MODEL WITH AND WITHOUT WINGLET

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MD. ALTAB HOSSAIN

October 2005

Chairman: **Associate Professor Prithvi Raj Arora, PhD**

Faculty: **Engineering**

The measurement of aerodynamic forces and moments acting on an aircraft model is important for the development of wind tunnel measurement technology. The primary purpose of wind tunnel measurements over the model for the forces and moments is to predict the performance of the full-scale vehicle. Force measurement techniques in wind tunnel testing are necessary for determining a variety of aerodynamic performance parameters. For three-dimensional aircraft models, forces and moments are usually measured directly using a balance system. The balance mechanically separates the total aerodynamic load on a model into its six aerodynamic components. Two fundamental types of balances, external and internal balances, are used today. External balances carry the loads outside the tunnel before they are measured and internal balances which fit in the model and are arranged to send data out through electrical wires.

In this research work, six-component external balance is commissioned and the calibration has been thoroughly checked and the detailed procedure of measurement of aerodynamic forces is recommended. A set of winglet has been designed for the existing aircraft model at the Aerodynamics laboratory of the Aerospace Engineering Department, UPM. Further the aerodynamic forces are measured on the aircraft model having a rectangular wing with and without winglet attached to the model. Tests have been carried out on the aircraft model with and without winglet at the Reynolds numbers 170,000, 210,000 and 250,000. The experimental results show that lift curve slope increases by 1-6% with the addition of certain winglet configurations and at the same time the drag decreases by 20-28% as compared to those for the aircraft model without winglet for the maximum Reynolds number considered in the present study.

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

PENYELIDIKAN TERHADAP CIRI-CIRI AERODINAMIK PADA ARAH MENDATAR KE ATAS MODEL PESAWAT BER "WINGLET" DAN TANPA "WINGLET"

Oleh

MD. ALTAB HOSSAIN

Oktober 2005

Pengerusi: **Profesor Madya Prithvi Raj Arora, PhD**

Fakulti: **Kejuruteraan**

Pengukuran daya dan momen aerodinamik yang bertindak ke atas sesebuah model pesawat adalah penting dalam pembangunan teknologi pergukuran untuk bagi terowong angin. Tujuan utama pengukuran daya dan momen tersebut terhadap model ialah untuk meramal prestasi saiz sebenar kenderaan yang diuji. Teknik pengukuran adalah perlu dalam menentukan pelbagai parameter prestasi aerodinamik. Untuk model sebuah pesawat tiga-dimensi daya dan momen diukur terus menggunakan debuah sistem imbangan. Sistem, imbangan memisahkan daya paduan keatas models kepada enam komponen aerodinamik. Dua jenis azas timbangan yang digunakan setakat ini iaitu timbangan luar dan timbangan dalam. Timbangan dalam menahan beban diluar terowong sebelum diukur dan timbangan dalam yang mana terpasang di dalam model dan diatur untuk mengirim data melalui wayar elecktrik.

Dalam kajian ini, enam komponen imbangan luaran diuji dan tentu ukur diperiksa dan prosedur terperinci mengenai pengukuran daya-daya aerodinamik dicadangkan. Satu set "winglet" telah direka untuk model pesawat sedia ada di makmal Aerodinamik Jabatan Kejuruteraan Aeroangkasa, UPM. Seterusnya, daya-daya aerodinamik terhadap model pesawat yang mempunyai sayap empat segi tepat dengan "winglet" dan tanpa "winglet" telah dianalise. Ujian telah dijalanka ke atas model pesawat dingan "winglet" dan tanpa "winglet" pada nombor "Reynolds" 170000, 210000 dan 250000. Keputusan eksperimen menunjukkan bahawa kecerunan lengkuk daya angkat meningkat 1-6% dengan menggunakan konfigurasi "winglet" tertentu dan dalam masa yang sama daya seret berkurangan sebangak 20-28% debgan membandingkan keputusan model pesawat tanpa "winglet" untuk nobmor "Reynolds" maksimum yang dipertimbangkan dalam kajian ini.

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I certify that an Examination Committee met on 19th Oktober 2005 to conduct the final examination of Md. Altab Hossain on his Master of Science thesis entitled "Longitudinal Aerodynamic Characteristics of an Aircraft Model with and without Winglet" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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Date: 8 DEC 2005

DECLARATION

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

MD. ALTAB HOSSAIN

Date: 18/11/05

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ABBREVIATIONS

AFFDL	Air Force Flight Dynamics Laboratory
BBJ	Boeing Business Jet
CNC	Computer Numerically Controlled
DOC	Direct Operating Cost
LaRC	Langely Research Center
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
OLWT	Open Loop Wind Tunnel
PSU	Pennsylvania State University
RPM	Revolutions Per Minute

LIST OF SYMBOLS

b	Wing span
c	Chord length
α	Angle-of-attack
D	Drag force
D_i	Induced drag
L	Lift force
M	Pitching moment
N	Newton
Nm	Newton meter
ρ_∞	Air density
S	Plan surface or reference area
AR	Aspect Ratio
e	Efficiency factor
δ	Constant
μ_∞	Viscosity of air
T	Ambient temperature
K	Kelvin
V_∞	Free stream velocity
Re	Reynolds number
M_∞	Mach Number
a_∞	Speed of Sound
R	Gas constant

q_∞	Dynamic pressure
C_D	Drag coefficient
C_{Di}	Coefficient of Induced drag
C_L	Lift coefficient
C_M	Pitching moment coefficient
$L/\bar{D}$	Lift/Drag
C1	Load No. 1
C2	Load No. 2
C3	Load No. 3
C4	Load No. 4
C5	Load No. 5
C6	Load No. 6
L_i	Signal Matrix
K_{ij}	Coefficient Matrix
F_i	Load Matrix

CHAPTER 1

INTRODUCTION

1.1 Background

One of the primary barriers limiting the performance of aircraft is the drag that the aircraft produces. This drag stems from the vortices shed by an aircraft's wings, which causes the local relative wind downward (an effect known as downwash) and generate a component of the local lift force in the direction of the free stream. The strength of this induced drag is proportional to the spacing and radii of these vortices. By designing wings, which force the vortices farther apart and at the same time create vortices with larger core radii, it may significantly reduce the amount of drag the aircraft induces. Airplanes which experience less drag require less power and therefore less fuel to fly an arbitrary distance, thus making flight, commercial, more efficient and less costly. One promising drag reduction device is the winglet. For a number of years many investigations have been carried out to prove the possible benefits of modifying wing tip flow. Tip devices have become a popular technique to increase the aerodynamic performances of lifting wings. The idea behind all the devices described is to diffuse the strong vortices released at the tip and optimise the span wise lift distribution, while maintaining the additional moments on the wing within certain limits (Filippone, 2004). Winglets have increasingly become a popular method of altering the trailing tip vortex system from an aircraft wing and thus improve the aircraft performance. A winglet is a device used to improve the efficiency of aircraft by lowering the lift-induced drag caused by wingtip vortices. A winglet provides an innovative method of achieving the vortex arrangement described above. The concept involves constructing wings whose tips are small extension in the form of a smaller aerofoil section placed at any angle, as shown in Figure 1.1.

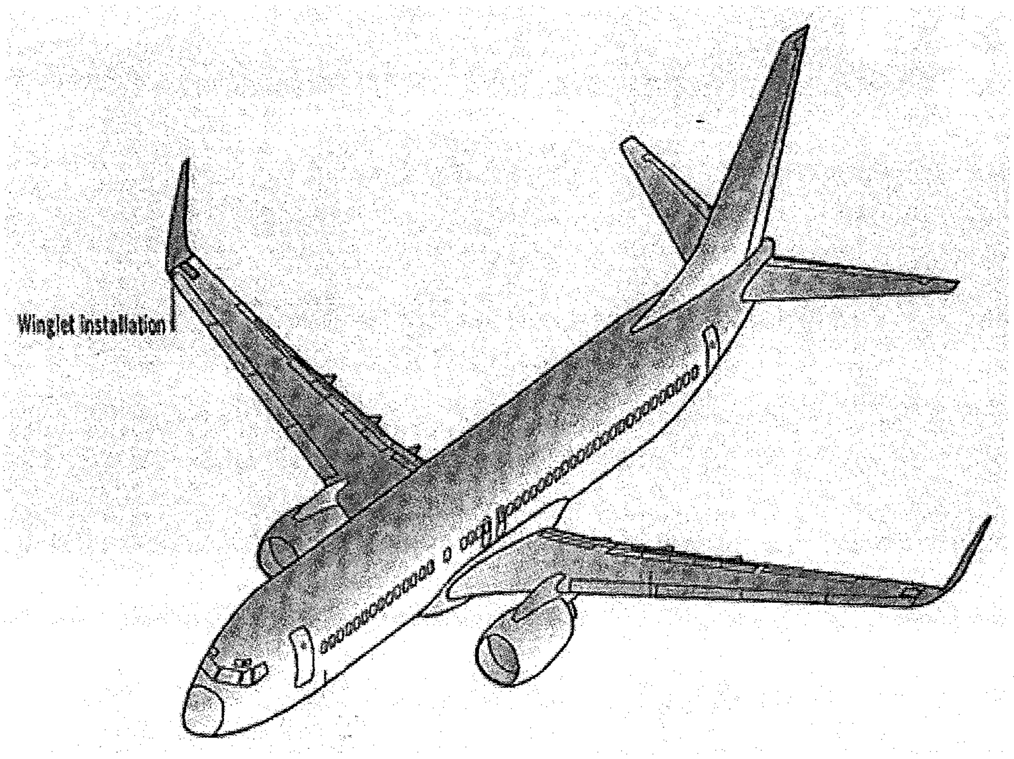

Figure 1.1: Airplane Configuration with Winglets (Boeing Commercial Airplanes, Washington).

Because the vortices shed by the wing are strongest at the tips of the wing, the addition of wing tip surfaces can reduce and diffuse the strength of these vortices, thus reducing the overall vortex drag of the aircraft (Asselin, 1997). Two pairs of winglets are used with the aircraft model existing in Aerodynamics Laboratory of Aerospace Engineering Department, Universiti Putra Malaysia. The longitudinal aerodynamic characteristics of aircraft model with two-winglet configuration have been the subject of this research work.

1.2 Problem Statement

The airfoil is the heart of an airplane it affects the cruise speed, takeoff and landing distances, stall speed, handling qualities (specially near the stall), and overall aerodynamic efficiency during all phases of flight. When wing is generating lift, it has a reduced pressure on the upper surface and an increased pressure on the lower surface. For a wing of finite span, the air on the upper surface flows inward and air below the under-surface flows outward. For this reason there is a continual spilling of the air round the wing tip from the bottom surface of the wing to the upper surface. These two airflows meet at the trailing edge and cause wing-tip vortices. If there is a wing of infinite aspect ratio, the air flows over the wing surface without any inward or outward deflection, and therefore no wing-tip vortices, no induced drag. But such a thing is impossible in practical flight, and for this reason the effective aspect ratio is increased as large as is practicable by using winglet. The extension of wingspan permit the lowering of drag but this comes at a cost of increasing the strength of the wing and hence its weight. This establishes the need for the winglet. Winglets work by increasing the aspect ratio of a wing without adding greatly to the structural stress and hence necessary weight of its structure.

The small extension at the wing tip is called winglet and is placed at any angle to the existing wing surface so that the rotating vortex flow at the wing tip creates a lift force on the winglet that has a forward component. This forward component of the lift force reduces the total wing drag. The idea behind the winglet is to produce a flow field that interacts with that of the main wing to reduce the amount of span wise flow. That is, the span wise induced velocities from the winglet oppose and thereby cancel those generated by the main wing.

The purpose of this investigation is to study the behaviour of an added winglet of varied geometries to a NACA 65-3-218 rectangular wing as a part of an existing aircraft model.

1.3 Objectives of the study

The main objectives of this research work are

1. To compare the calibration matrix with calibration matrix provided with the six-component external balance as supplied by the manufacturer.
2. To design and fabricate a set of winglet for the existing aircraft model at the Aerodynamics Laboratory of the Aerospace Engineering Department, UPM.
3. To measure the lift and drag forces and pitching moment of the aircraft model having a rectangular wing with and without winglet attached to the model by using six-component external balance at the Aerodynamics Laboratory of the Aerospace Engineering Department, UPM.
4. To compare the experimental lift force, drag force and pitching moment for the modified wing of an existing aircraft model with an elliptical and a circular winglets of given aspect ratio with the results obtained through the unmodified aircraft model.

1.4 Organisation of the Thesis

The dissertation is divided into five chapters. In chapter one, the requirements of winglet in the Aerospace industry for the aircraft model are discussed. This chapter