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ANALYSIS AND OPTIMIZATION OF INCOMPRESSIBLE INVISCID FLOW AROUND SPLIT FLAP AIRFOILS

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By

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To the authors' kind parents;

Mohamed Ahmed and Hauwa

and to his beloved sons;

Algaili and Mohamed

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LIST OF ABBREVIATIONS

c	Airfoil chord
C_d	Drag coefficient
C_l	Airfoil lift coefficient
$C_{l\,max}$	Maximum lift coefficient
$C_{l\alpha}$	Slope of lift curve
C_p	Pressure coefficient
$C_{pi\,lower}$	Pressure coefficient at the control point of the *ith* panel on lower surface of the airfoil
$C_{pi\,upper}$	Pressure coefficient at the control point of the *ith* panel on upper surface of the airfoil
l	Length of stream line
l_i	Length of *ith* panel
P	Static pressure
P_∞	Pressure of free stream
q	Source strength
q_i	Strength of source distribution in *ith* panel
r_{ij}	Distance from *jth* node to the control point of the *ith* panel
(r, θ)	Global polar coordinates
S	Airfoil platform area
V	Velocity of flow
V_{ni}	Normal velocity component at control point of the *ith* panel

V_{ti}	Tangential velocity component at control point of the *ith* panel
V_{∞}	Velocity of free stream
u	Global velocity component in direction of the x-axis
u_i	Global velocity component in direction of x-axis at control point of the *ith* panel
u_{sij}	Global velocity component in direction of x-axis at control point of the *ith* panel due to unit strength source distribution at the *jth* panel
u^*	Local velocity component in direction of the x-axis
u^*_i	Local velocity component in direction of x-axis at control point of the *ith* panel
u^*_{sij}	Local velocity component in direction of x-axis at control point of the *ith* panel due to unit strength source distribution at the *jth* panel
v	Global velocity component in direction of the y-axis
v_i	Global velocity component in direction of y-axis at control point of the *ith* panel
v_{sij}	Global velocity component in direction of y-axis at control point of the *ith* panel due to unit strength source distribution at the *jth* panel
v^*	Local velocity component in direction of the y-axis
(x , y)	Global Cartesian coordinates
(x^* , y^*)	Local Cartesian coordinates
Y	Airfoil surface function
α	Angle of attack
α_{cl0}	Zero lift angle of attack
α_{incr}	Effective increment in angle of attack due to flap deflection
β_{ij}	Angle suspended at control point of the *ith* panel by the *jth* panel

γ	Vortex strength
γ_i	Strength of vortex distribution for the *ith* panel
Γ	Circulation
π	Ratio of circle circumference to it's diameter
ϕ_s	Source potential
ϕ_v	Vortex potential
ϕ_∞	Velocity potential for free stream
ψ	Stream function
∞	Infinity
ω	Angular velocity
ρ	Air density

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Chairman: Assoc. Prof. Dr. ShahNor Basri

Faculty: Engineering

Generally airfoils are designed for cruise flight conditions; but during take-off and landing, when the airplane flies at low speeds and small angles of attacks, the lift provided by single airfoils is not sufficient, and an extra lift is required for safe landing and take-off. In this condition the use of high lift devices is important. When an airfoil is accompanied by high lift devices the system is referred to as multi-component airfoil configuration. When high lift devices are deflected, the geometry of the airfoil is changed temporarily. As a result the effective chamber, angle of attack, and area of the airfoil are increased; consequently, the lift is increased too, since the lift is directly proportional to the chamber, the angle of attack, and the airfoil area. The advantage of this is that the landing and take-off speeds are reduced, a fact that gives the pilot more time to react, in case any accident happens during take-off or landing. At the same time, the runway length is also reduced. If the airplane is fast and it's carrying capacity is high, then the importance of using multi-

component airfoils increases, because the value of the lift increment necessary for safe take-off and landing is high.

At the present time, the importance of multi-component airfoils is increasing due to the high competition between airplane manufacturing companies, whose aim is to produce new models of airplanes with higher speeds and carrying capacities than the airplanes used today. Future airplanes should be fast, safe, and large. Achievement of these requirements in future airplanes is strongly related to the use of the appropriate multi-component airfoil designs. And this is why much experimental and computational work needs to be devoted to analyze and optimize the flow around multi-component airfoil configurations.

When dealing with multi-component airfoil configurations computational methods are of great importance so as to focus the zone of the optimal flap position for the maximum lift coefficient. Then the experimental work is to be carried out within that zone. This saves long expensive wind tunnel, and flight test hours.

In the investigation presented in this thesis, a computer program, which models incompressible inviscid flow around an airfoil with a split flap, has been developed. The program is based on the pioneering Hess and Smith panel method. The new program is referred to as MULTFOIL.

Absrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia sebagai memenuhi syarat ijazah Sarjana Sains.

ANALISIS DAN PENGOPTIMUMAN ALIRAN TAK BOLEH MAMPAT TAK LIKAT DISEKELILING AIRFOIL DENGAN KEPAK PISAH

Oleh

OSMAN MOHAMED AHMED

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Fakulti : Kejuruteraan

Pada amnya, airfoil direkabentuk untuk keadaan jajap penerbangan; tetapi ketika penerbangan dan pendaratan dilakukan, apabila kapal terbang pada kelajuan yang rendah dan sudut serang yang kecil, airfoil tunggal menghasilkan seretan yang tidak memuaskan dan seretan tambahan diperlukan untuk pendaratan dan penerbangan yang selamat. Dalam keadaan ini, penggunaan peranti seretan tinggi adalah penting. Bila airfoil diikuti dengan peranti seretan tinggi, sistem tersebut dirujuk sebangai tataraja berbilang komponen airfoil. Apabila peranti seretan tinggi dipesongkan, geometri airfoil berubah; dengan itu, seretan juga bertambah, selagi seretan berkadaran terus dengan kebuk, sudut serangan dan kawasan airfoil. Kebaikan yang diperolehi adalah pendaratan dan kelajuan penerbangan berkurangan, kesannya memberikan juruterbang lebih masa untuk bertindak dalam sebarang kes kemalangan yang mungkin berlaku ketika penerbangan atau pendaratan. Pada masa yang sama, jarak landasan juga berkurangan. Sekiranya kapal udara laju serta

membawa kapasiti yang tinggi, maka kepentingan penggunaan berbilang komponen airfoil bertambah, ini disebabkan nilai tokokan seretan yang semestinya untuk keselamatan pendaratan dan penerbangan adalah tinggi.

Pada ketika ini, kepentingan berbilang komponen airfoil bertambah bergantung kepada persaingan yang tinggi antara syarikat pembuatan kapal udara, dimana usaha mereka untuk mengeluarkan model baru bagi kapal terbang dengan kelajuan yang tinggi serta membawa kapasiti berbanging dengan kapal terbang yang digunakan hari ini. Kapal terbang masa akan datang seharusnya laju, selamat dan besar. Pencapaian bagi permintaan ini dalam kapal udara masa akan datang adalah berkaitan kuat dengan penggunaan rekabentuk berbagai komponen airfoil yang sesuai. Ini menyebabkan, ujikaji dan analisis berangka diperlukan untuk menukarkannya kepada analisa dan optimasi aliran sekeliling pengiraan berbilang komponen airfoil.

Apabila menyentuh tentang kaedah pengiraan tatarajah berbilang komponen airfoil yang sangat penting untuk memfokuskan zon optimum posisi kepak bagi pekali daya angkat yang maksima. Kemudian kerja ujikaji dibawa keluar dalam zon tersebut. Ini akan menjimatkan terowong angin yang panjang dan mahal serta masa ujian penerbangan.

Kajian yang diterangkan di dalam tesis ini adalah aturcara komputer, dimana model-model disepanjang aliran tak likat tak mampat airfoil dengan kepak pisah yang telah dibina. Aturcara ini bergantung kepada penemuan kaedah panel Hess dan Smith. Aturcara yang baru ini adalah dikenali sebangai MULTFOIL.

CHAPTER I

INTRODUCTION

Wings are of great importance in aeroplane design, because they provide the lifting force which raises the aeroplane from the ground to safe cruising heights. Aeroplane wings' aerodynamic characteristics strongly depend on airfoils aerodynamic characteristics, especially the lift, the drag, and the pitching moment coefficients (Clancy, 1975).

The airfoil concept was first introduced by Langley and Wright Brothers who performed the first flight in history in December 1903 (McCormick, 1995). Following this famous historical event, considerable amount of theoretical and experimental efforts have been devoted to the development of airfoils. Most of this work was done by the National Advisory Committee of Aerospace (NACA), and the National Aeronautics and Space Administration (NASA) in the United States of America (McCormick, 1995).

When an airfoil is accompanied by one or more leading or trailing edge flaps, or a slat, the whole system is referred to as a multi-component airfoil. This introduction is intended to give a clear idea about the concept and importance of multi-component airfoil configurations as well as explaining the aims of the current research.

Multi-Component Airfoils

There are many possible designs for multi-component airfoil configurations which may be composed of two or more components. Figure 1 shows three designs of multi-component airfoil configurations while in Figure 2 a schematic drawing of a single component airfoil is shown.

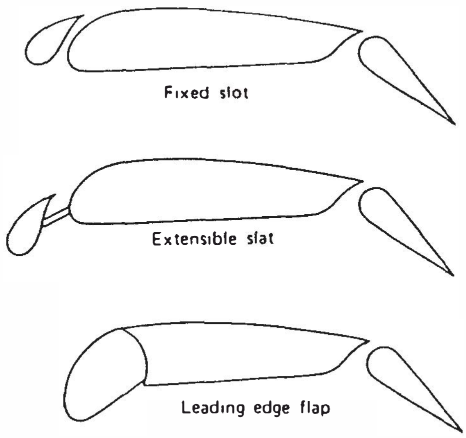

Figure 1: Some Multi-Component Airfoil Configurations (McCormick, 1995).

Figure 2: A Typical Single-Component Airfoil (Moran, 1984).

In a multi-component airfoil configuration the original airfoil is called the base airfoil; the flaps and slats are called high lift devices, for they are deflected mainly in order to maximize the lift coefficient. At the present time, the importance of multi-component airfoils is increasing due to the high competition between airplane manufacturing companies, whose aim is to produce new models of airplanes with higher speeds and carrying capacities than the airplanes used today (McLean, per. comm., 1996). The future airplanes should be fast, safe, and large in a world of business which is governed by profit and loss metrics. In fact, studies have already been started so as to manufacture supersonic large commercial airplanes (McLean, per. comm., 1996). The achievement of these requirements in future airplanes is strongly related to the use of the appropriate multi-component airfoil designs (McCormick, 1995).

Generally airfoils are designed for cruise flight conditions; but during take-off and landing, when the airplane flies at low speeds and small angles of attacks, the lift provided by the single airfoil is not sufficient, and an extra lift is required for safe landing and take-off. In this condition the use of high lift devices is important. When a high lift device is deflected the geometry of the airfoil is changed temporarily. As a result the effective chamber, the effective angle of attack, and the effective area of the airfoil are increased; consequently, the lift is increased too, since the lift is directly proportional to the chamber, the angle of attack, and the airfoil area. The advantage of this is that the landing and take-off speeds are reduced, a fact that gives the pilot more time to react, in case any accident happens during take-off or landing.

At the same time, the runway length is also reduced (McCormick, 1995). If the airplane is fast and its' carrying capacity is high, then the importance of using multi-component airfoils increases, because the value of the lift increment necessary for safe take-off and landing is high.

Aims of the Current Research

The objective of dealing with the problem of multi-component airfoils is to find the optimal flap position for the maximum lift coefficient. Two approaches will be put into consideration; the first is experimental and second one is theoretical. The theoretical approach is based on computational solutions and mathematical modeling of the flow, whereas the experimental approach utilizes the wind tunnel experimental testing. To search for the optimal flap position experimentally it requires expensive long wind tunnel hours. For example, if a wind tunnel experiment is to be carried out so as to find the optimal flap position for an airfoil with a trailing edge flap, the experiment has to be repeated many times for each flap deflection until the maximum lift coefficient is achieved; in the case of a three-component airfoil configuration the number of trials needs to be at least doubled. Therefor; quick, reliable, and less expensive methods are required to solve the problem.

For the present research, a computer code has been developed to calculate the lift coefficient for a two-component airfoil configuration (an airfoil with a split flap). This code is based on Hess and Smith panel method (Hess and Smith, 1966), which is one of the pioneering panel methods that utilizes the potential flow theory (Moran, 1984). The potential flow theory and Hess and Smith panel method are discussed in details in Chapters III, and IV respectively. The code is referred to as MULTFOIL.

This thesis consists of six chapters. The first chapter contains the introduction and aims of the research. Chapter II deals with the literature review, which includes topics related to the multi-component airfoils problem.

Chapter III addresses the theoretical aspects of numerical modeling carried out for multi-component airfoils. This chapter treats in detail the fundamental theory of potential flow. Chapter IV caters computational algorithm of the code. Also, in this chapter, some samples of computed results are compared with the corresponding experimental results for validation. In Chapter V, results for some selected airfoils, each with a 20% split flap at various angles of deflection are illustrated and discussed. Chapter VI will be the conclusion, and recommendations for future work.

CHAPTER II

LITERATURE REVIEW

Introduction

The Wright Brothers who carried out the first flight in history in December 1903 (McCormick, 1995), were very confident in their research results. They built their own wind tunnel and tested hundreds of different airfoils and wing platform shapes (McCormick, 1995). The results which they published at that time showed that they were aware of the airfoil problem together with the related basic concepts such as energy, work, statics, and dynamics. The views of Wright Brothers first aeroplane are shown in Figure 3 (McCormick, 1995). The Wright Brothers airfoils were based on experimental work only without using any analytical or theoretical methods.

Today, results of early experiments performed in a very rational way like those of Wright Brothers can be explained by applying well established aerodynamic principles that have been developed over the years from both analysis and experimentation. In this chapter, development of airfoil design and theoretical aerodynamics principles are going to be reviewed, as well as methods used in experimental aerodynamics.

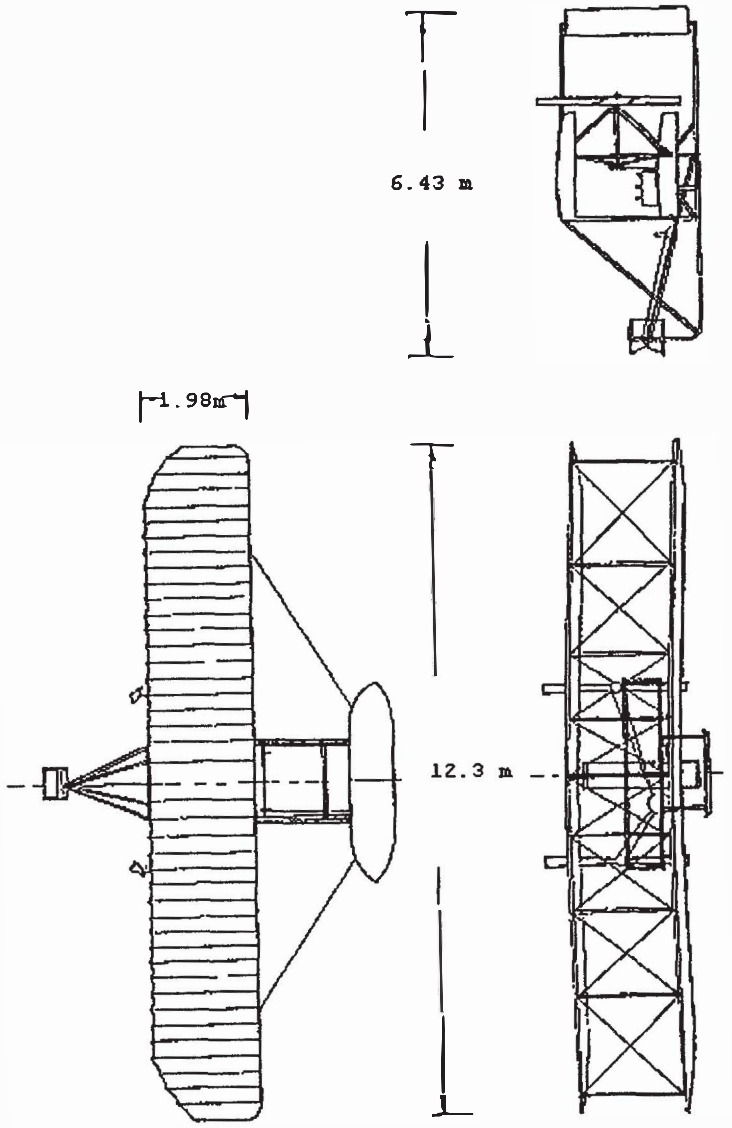

Figure 3: Views of the First Airplane Used by Wright Brothers in 1903

(McCormick, 1995).

Airfoil Design Development

In this section, the airfoil design development is discussed by reviewing various families of airfoils which have been developed; the advantages and the disadvantages of each will be shown. The first airfoils designed to fly an airplane were those of the Wright Brothers, as mentioned before. In 1932, the National Advisory Committee of Aeronautics (NACA) tested a series of airfoil shapes known as NACA four-digit airfoils. Tests carried out before this indicated the desirability of a rounded leading edge and sharp trailing edge; which is considered in designing this family of airfoils (Abbott, 1958). The thickness distribution and the chamber line of NACA four-digit airfoils are given as functions of the x-coordinate taking the leading edge as the origin (Abbott, 1958).

NACA five digit airfoils were developed around 1935. The tests of NACA four-digit airfoils indicated that the maximum lift coefficient could be increased as the position of maximum chamber was shifted either forward or aft of approximately the mid-chord position. The rearward position is not desired because of the large pitch moment coefficient. The mean line used in NACA four-digit airfoils was not suitable for extreme forward positions of maximum chamber. Thus a new series of mean lines was developed and the result was NACA five-digit airfoils. The thickness distribution is the same as that for NACA four-digit airfoils. The mean lines are defined so as to produce shapes having progressively decreasing curvatures from aft the leading edge. The curvature decreases to zero at a point slightly aft the position of the maximum chamber to remain zero till trailing edge (Abbott, 1958).