THE EVALUATION OF LIFT AND DRAG FORCE FOR SOLID BODY WITH MICRO DIMPLE

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ABSTRAK

Kajian ini meneroka daya angkat dan mekanisme daya seretan, taburan tekanan di sepanjang kord dan aliran visualisasi aerofoil yang mempunyai lubang- lubang kecil di atas permukaan aerofoil dengan tujuan penilaian kesan takik pada ciri aerodinamik aerofoil. Kajian reka bentuk dan parameter rongga-rongga tersebut yang optimum dalam meningkatkan prestasi aerodinamik turut dijalankan. Isu-isu mengenai penggunaan bahan api, kos tenaga, kecekapan prestasi aerodinamik untuk kegunaan aerofoil dalam mesin, automotif terutama dalam keadaan cuaca yang tidak dijangka seperti pergolakan udara yang mengganggui penerbangan udara disebabkan tahap prestasi aerodinamik aerofoil yang tidak memberangsangkan telah memberikan impak kepada penyelidik untuk meningkatkan prestasi aerodinamik dari semasa ke semasa. Dalam konteks semasa, interaksi antara parameter lubang-lubang kecil telah dipertimbangan dan perbezaan bentuk silinder dan heksagon telah dipraktik. Aerofoil bersaiz 0.14m x 0.148m diuji di bawah terowong angin dengan sudut serangan yang berbeza dan variasi halaju udara. Penggambaran aliran asap melalui permukaan aerofoil bawah ujian asap ditangkap dengan kamera kelajuan tinggi. Dapatan menunjukkan lekukan mampu prestasi daya angkat aerofoil meningkat seiring dengan pengurangan daya seretan. Kenyataan ini dibukti dengan kelewatan pemisahan aliran akibat dari kepusaran aliran (vorticity) yang berterusan mengurangkan seretan geloraan permukaan aerofoil, seterusnya meningkatkan daya angkat dan penguasaan aerofoil. The aerofoil lekuk silinder dengan nisbah aspek diameter dengan kedalaman 0.4 dan jarak lekuk 8500 mikron disyorkan dengan memberikan daya angkat yang paling tinggi dan daya seretan yang paling rendah antara semua model yang dikaji.

ABSTRACT

The present study explores the lift and drag mechanism, pressure distribution along the chord and flow visualization of the debossed dimpled- aerofoil with the aim to evaluation the effect of dimples on the aerodynamic characteristic on the aerofoil and find an optimisation on the dimples parameter in improving the aerodynamic performance. The issues on the fuel consumption, energy cost, aerodynamic performance efficiency for aerofoil application in turbine, automotive especially under unexpected weather condition such as air turbulence in air flight lead to the concern on improving the aerodynamic performance from time to time. In current context, the interaction of the dimple parameters influencing the aerodynamic behaviour of the aerofoil such as the dimple aspect ratio, shape, pitch resulting in variation of number of dimple is considered. An aerofoil sized 0.14m x 0.148m is tested under wind tunnel with different angle of attack and air velocity. The aerofoil flow visualizations under smoke test are captured with a high speed camera. A comparative study of the smooth and dimpled aerofoil with cylindrical (bluff) and hexagonal (blunt) dimple shape is investigated. From the result it is shown with the integration of dimple, the lift performance of the aerofoil is greatly improved with the delay of flow separation as a result from the streamwise vorticity reduces the turbulent skin drag. thus increasing the lift and the controllability of the aerofoil. The cylindrical dimpled aerofoil with the aspect ratio of 0.4 and pitch 8500 µm is highly recommended with the highest lift and lowest drag.

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LIST OF SYMBOLS

α	-	Cronbach’s alpha
A_{model}	-	The area of current aerofoil model
A_{scaled}	-	The area of the scaled aerofoil for validation
AOA	-	Angle of attack
C_D	-	Drag coefficient
C_L	-	Lift coefficient
c	-	Chord length
d	-	Dimple diameter
F_D	-	Drag force
h	-	Depth of dimple
λ	-	Dimple aspect ratio
L	-	Length of pressure point along chord
ρ	-	Density of fluid (air)
P	-	Pitch of the dimple
Re	-	Reynold number
s	-	Span length
μ	-	Dynamic viscosity of fluid(air)
v	-	Velocity of fluid

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The use of dimple in the design of a product is first introduced in the sense of golf ball dynamics in 1800's. This design has helped the industry of golf ball till today which is the dimple structure design is patented by the William Taylor, the engineer originated from England. Dimples was officially first introduced in the game of golf in 1905 as the English engineer William Taylor registered a patent. It had been brought to Taylor attention that golf players tried to make irregularities in the ball under the impression that it would cause an increase in the length of their shots, which studies performed by Taylor also implied. Though in most cases the formation of irregularities is unfavourable by the researcher, the impact of dimples in helping reducing the wake drag is truly astounding. Considering a perfectly smooth and frictionless sphere, with the symmetrical air flow resulting in symmetrical pressure distribution too. In another meaning, the wake region of the sphere will be very big, the drag force in front of the ball, attempting in slowing the ball, is cancelled by the equal yet opposite force of the rear part. Minimal lift is produced. In such circumstances, the integration of dimples fosters a series of flow disturbance that delaying the flow separation on spherical body.

Livya *et. al.* [6] study the effect of the dimple by introducing dimples on the aircraft wing will create turbulence by creating vortices which delays the boundary layer separation resulting in decrease of pressure drag and also increase in the angle of stall. Boundary layer formation and drag forces attributed to the fluid flow over an objects surface, provides an understanding of the performance of the object itself.

Research has been focused on reducing forces related to fluid flow in order to allow for greater performance of the object whether it is stationary or dynamic. Surface finishes and shapes are the main focus of ongoing research in performance areas such as ballistics and sporting. One of the techniques of this research is the surface application of 'dimples'. Fluid flow characteristic contributed to the presence of dimples develop complex reaction structures. Due to this complexity research on dimples in immersed fluid flow has been conducted in order to develop a greater understanding of these flow structures[7].

The streamline bodies have been applied particularly in the aircraft, automotive and turbomachinery sector. The driving of the need to search for the enhancement of the aerodynamic performance in the blunt bodies propose several type of the solution to the aerofoil especially. Dimples are one kind of the passive vortex generator that do not need energy or actuator to generate the pulsed frequency for the vortex formation to create turbulent boundary layer. Though in certain research dimples can divide into outward dimples or indented research[6] but for most of the researches the dimple will be referred to the debossed indentation into the surface of the solid bodies. Those with sensor or actuator vortex generator will be defined as active vortex generator. Dimples design will be affected by various parameter such as the diameter of the dimple to the depth aspect ratio, shapes, pitch which represent the distance between two dimples as well as the arrangement of the dimples. Dimple is also used in the safety of automotive implements in the tyre antihydroplanning performance [8].

Enhancing an aerodynamic efficiency (L/D) is one of the key parameter that determines performance of an aircraft. Aerodynamics efficiency is important to aircraft system for both commercial and military to have better control over the aircraft especially under the unexpected weather or air turbulence in the sky. Skin friction drag is a critical issue in the aircraft system where it will reduce the aerodynamic efficiency of the aircraft, thus reduces the stall angle in the aircraft. Improved stall angle to ensure the safe landing of an aircraft [6]

Kensrud (2010) claims that stalling during landing due to the reduction in dynamic pressure need to compensate by increasing the angle of attack. In the stalling case, the wing of the aircraft unable to produce the adequate lift to balance weight which will then lead to the flow separation that result in the increasing of drag, thus reducing the L/D ratio [9]. For the turbomachinery or wind turbine application, the horizontal axis wind turbine (HAWT) blade particularly will need to run the machine from 0° to 90° no matter in stalled or unstalled situation [10].

Boundary layer is formed when a fluid moves across an submerged objects in the direction of the fluid flow. The boundary separation causes viscous friction or a ‘drag force’ on the immersed object [11]. The unfavourable drag occurrence in the solid bodies which has led to streamlined designs for many modern requirements such as vehicles, airfoils, pipes, sporting equipment, firearm projectiles and many more fluid affected components. Reducing drag on objects produces benefits such as smaller energy losses, better performance and flight stability. Examples of how drag is diminished can be seen in many different variations. Some include flow disrupting fins seen on modern cars and airfoils, special paint applications on high performance vehicles including race cars and aircraft, sleeker helmet designs for professional bike riders and dimpled surfaces for golf balls.

Apart from drag there are several other important fluid flow characteristics that exist with dynamic flow on immersed objects. One characteristic is boundary layer production along the surface of an object. The design of this layer depends on several fluid attributes including the Reynolds Number, density, velocity, viscosity and temperature. The shape and surface finish of the object will affect the boundary layer also. The nature of the boundary layer also affects the aerodynamic efficiency as well. Previously more researcher will doubt the capability of dimples in generating more lift and reduce the drag meanwhile as the formation of the vortex will be always unfavourable for most of the application of fluid mechanics and aerodynamic systems. However, the turbulent boundary layer is claimed to be more susceptible to the adverse pressure gradient to continue flowing without a separation, though separation does occur, the pressure recovery process may take place.

Another important characteristic is flight stability. The stability of an immersed object is relied upon for predictability during performance. Fluid flow can be unpredictable in nature for example the erratic behaviour of wind currents over objects that rely upon constant flow performance can be affected by unexpected fluid movement. Designs for these objects compensate for these unpredictable events. An example is the surface design for formula one race cars; side winds are reflected at angles that produce down force instead of lift. This effect decreases lifting forces on the vehicles that could otherwise diminish the control that the driver has while racing. The present study will investigate drag and lift as well as fluid flow characteristics of dimpled surface aerofoil immersed in a dynamic flow and their resulting streamline from the integration of the micro-dimples to the surface of aerofoil.

1.2 Problem Statement

The study of forces reacting on the solid body sink in the fluid (air or water) is the crucial to human life. In the conjunction to the realisation, magnificent work has been initiated by many researchers in the past [12]. In general flow around streamline body, the boundary layer near the leading edge is thin and laminar while increasing it thickness toward the trailing edge. At a certain distance from the leading edge is a transition region in which the boundary layer changes its nature to turbulent. Despite the turbulent nature of this area, there is still a thin laminar sub layer where there is no turbulence on the aerofoil surface. This is due to the dampening effects of previously mentioned viscosity. This sub-layer slows down and becomes the cause of separation and reverse flow, and thus the wing stall. To avoid separation, but rather delay the formation and reduce the intensity of separation, the slowing layer should be accelerated and "energize". Throughout the years, many researcher embarks on various attempts on controlling the boundary layer to avoid the aerodynamic performance related to the flow separation. One of the proposed idea is turbulators or vortex generators are used to creates a swirling wake who places energy in the boundary layer of the wing to raise critical angle of attack, a lower stall speed, gentle stall characteristics, and therefore result to less tendency to "drop the wing". However, the study on the design and type of the vortex generator such as the use of dimple have not reached a consensus.

To date, the resolution of resolving drag and lift enhancement using dimples has received scant attention in the research literature. Coming to recent years, the dimple design in golf in early ages as well as the utilization of dimple in tribology and heat transfer have provoked the idea of the integration of micro-dimple in determining the drag and lift force of the solid body with micro dimple. Plus, despite the disadvantage of the drag to the flow of the solid body, a systematic understanding on the drag reduction mechanism through micro-dimple still remain unclear and ambiguous for most of the research as far as the author concern, there are too little details or barely find the studies on the study of micro-dimples on the aerodynamic effect of the solid body for the drag and lift mechanism.

In the early ages, more studies are done on the golf[13, 14] and dimpled cylinder [15] compared to aerofoil. The application of the bluff bodies and blunt bodies in daily life including the pipe flow, the bird or plane flight, racing car and others drives the importance of the study on the lift and drag on those application as well as the pressure distribution to detection how the changes in the pressure distribution lead to the fluctuating of the lift and drag that affecting the aerodynamic efficiency. The sad case is that in contrast to bluff bodies, there is much less information about effects of micro-dimple on the aerodynamic characteristics of the blunt bodies of aerofoil as dimples are more popularized in the use of bluff body compared to blunt body structure.

There are considerable researches on the characteristic of the dimples affecting the flow pattern of the solid body. To illustrate, Ting [16] studied the effects of dimple width and depth on the aerodynamic characteristics for a golf ball by CFD. Aoki[14] studied the effects of dimple number, depth and shape on the aerodynamic characteristics for a golf ball by some experiments and CFD (LES). Yet, these researches are focused on the macro-size dimples rather than micro-dimples and more rely on numerical simulation[6, 15, 17, 18] data rather than experimental research. This urge a need to have a method shift from numerical result to experimental data in order to obtain the real world practicality data as the current and previous experimental results more on demonstrating the raw data of drag and lift rather than connecting them to the flow pattern. They are more depend on the numerical streamline result for description of the drag and lift. Furthermore, there is lack of study of the relationship between aerofoil model NACA 0015 and the characteristic of micro-dimples.

1.3 Objective

The objectives of the present study are

a. To evaluate the aerodynamic behaviour of the solid bodies with micro-dimples.
b. To study the flow mechanism of aerofoil with dimples in drag reduction and lift enhancement system
c. To determine the recommended combination of dimple shape and geometry for aerodynamic performance enhancement

1.4 Significance of Research

The study of drag and lift force study of aerofoil are very important in the aerospace field as well as the turbomachinery for the turbine use. In the current research, a few research questions are significant in solving the stalling effect of the aircraft and turbomachinery by integrating the surface of the aerofoil with the micro-dimple. Is the drag force can be reduced by utilizing the micro-dimpled surface? Is the lift coefficient can be enhanced using the dimples? How are the flow patterns of the aerofoil with the micro-dimple surface? And how are the pressure distributions resulted with the integration of the micro dimple on the surface of the aerofoil? How the micro-dimpled surface affecting the fluid flow on the surface of the aerofoil and what are the consequences of the flow disturbance on the aerofoil lead to the fluctuation of the wake region in the flow pattern of micro-dimpled aerofoil? What are the mechanism of the designed dimples that help in improving the aerodynamic performance of the aerofoil? These can be obtained the answer from the current research.

1.5 Scopes

The scopes of this project are summarized as follows:

a. Solid bodies will be constructed using 3D printer.
b. Wind tunnel will be used in this experiment.
c. The temperature set in the wind tunnel test is the surrounding temperature ≈ 27°C.
d. The aerofoil model used is NACA 0015.
e. Test section of the wind tunnel is 0.3m x 03m.
f. The shape of the dimples are limited to cylindrical and hexagonal shape.
g. The size of the aerofoil must not bigger than the test compartment of test tunnel.
h. The research is focused on experimental study only.

1.6 Theoretical Framework

The present study will study about how surface roughness will give an impact to lift and drag as well as the pressure distribution and the change in boundary layer. The current study will focus on the experimental mean using the wind tunnel test. The theoretical framework of the present study is simplified as in the Figure 1.1

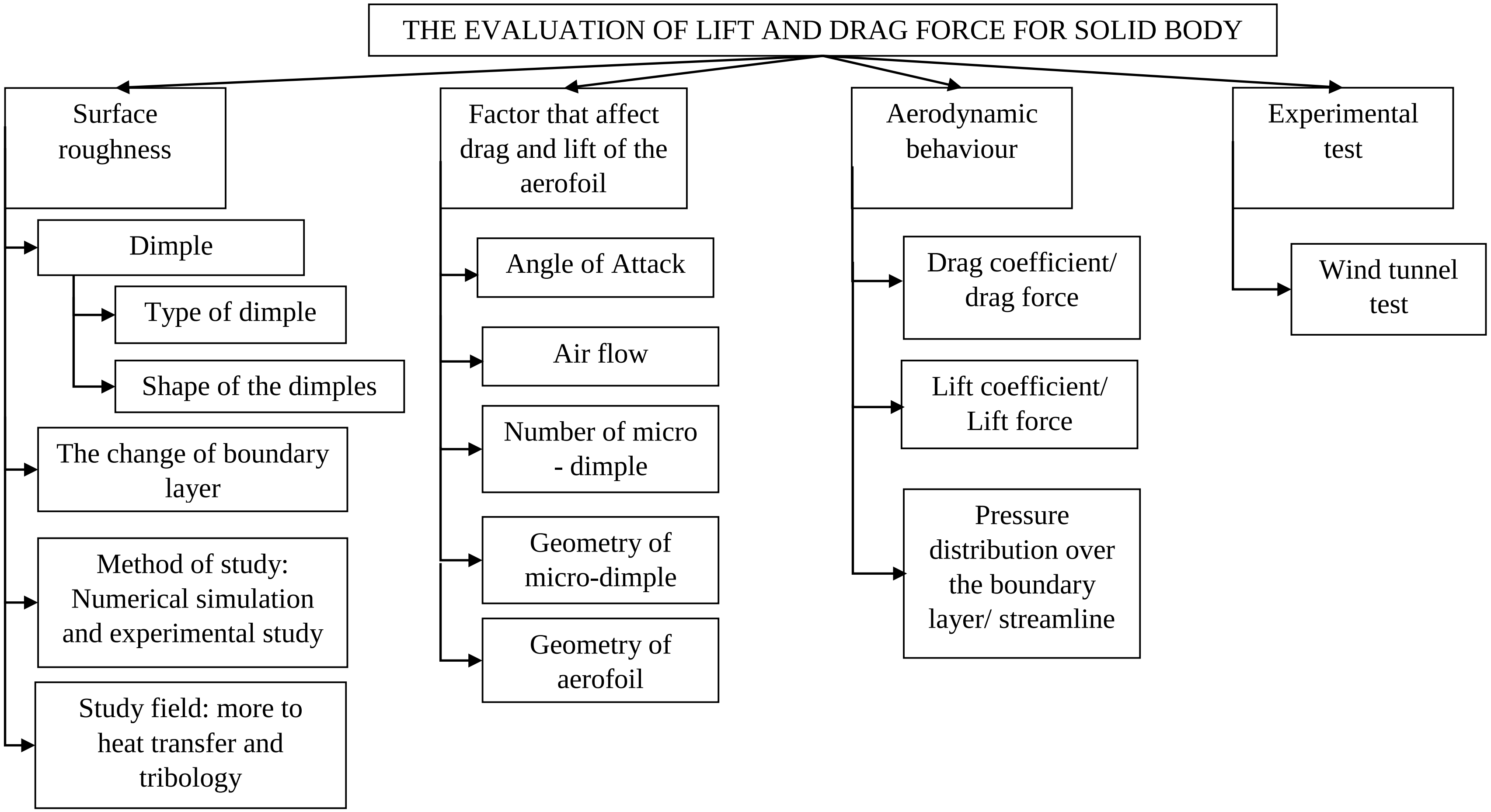

Figure 1.1 Theoretical framework of the current study

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