UNIVERSITI PUTRA MALAYSIA

EFFECTS OF UPSTREAM SQUARE BLOCKAGE ON LIFT BEHAVIOUR OF A ROTATING CYLINDER

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By

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January 2016

Chairman : Azmin Shakrine Bin Mohd Rafie, PhD
Faculty : Engineering

The usage of Unmanned Aerial Vehicle (UAV) is getting more and more significant in both the defense and commercial industry. As these UAVs normally carry a high payload and require a long runaway, it is important to develop a new method to increase the lift coefficient during takeoff and landing. The objective of the study is to study the lift generated by rotating cylinder at different spin rate at typical takeoff speed and also the effect upstream square blockage towards the lift generated by the rotating cylinder. Both wind tunnel experimental testing and numerical simulation was carried out to investigate the effect of different size of upstream blockage towards the performance of the rotating cylinder. The simulation adopted a fully turbulent flow, having Reynolds number varying from 5000 to 8000 and angular velocity of rotating cylinder varying from 0 to 3000 RPM. Validation of RANS code ANSYS Fluent was done with experimental results. The simulations results suggest that the blockage with the height of 32mm and 40mm, width of 8mm with a distance of 48mm from the center of the rotating cylinder will be the best configuration with near to tenth fold improvement in lift generation

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

KESAN BLOK YANG DILETAK DI HADAPAN SILINDER BERPUTAR TERHADAP DAYA APUNGAN YANG DIJANAKAN

Oleh

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Pengerusi : Azmin Shakrine Bin Mohd Rafie, PhD
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Diperhatikan kerperluan untuk Unmmaned Aerial Vehicle (UAV) semakin meningkat sama ada untuk industri pertahanan atau industri swasta. UAV jenis biasanya mempunya beban yang tinggi dan memerlukan landasan yang panjang untuk berlepas dan mendarat. Oleh itu, adalah pentingnya untuk mengaji cara baru untuk meningkatkan daya apungan UAV semasa berlepas dan mendarat. Penyelidikan ini bertujuan untuk mangaji daya apungan silinder berputar pada kelajuan berlepas dengan putaran yang berbeza, blok yang berbeza siaz juga dikaji untuk mengaji pengaruhnya terhadap silinder berputar..Eksperimen dengan menggunakn terowong angin dan simulasi berangka telah dijalankan untuk mengkaji kesan bagi saiz blok yang berbeza terhadap prestasi silinder berputar. Simulasi yang dijalankan mengambil kira kesemua bergeloraan dengan Reynolds number dari 5000 to 8000, silinder juga berpusing dengan RPM dari 0 hingga 3000 RPM. RANS code ANSYS Fluent telah disahkan dengan data eksperimen . Data-data menunjukkan bahawa blok dengan ketinggian 32mm dan 40mm, lebar 8mm dan diletakkan 48mm dari pusat silinder dapat memberikan peningkatan daya apungan yang paling tinggi terhadap silinder berputar sehingga sepuluh kali ganda.

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I certify that a Thesis Examination Committee has met on 27 January 2016 to conduct the final examination of Cheong Xiang Hou on his thesis entitled "Effects of Upstream Square Blockage on Lift Behaviour of a Rotating Cylinder" 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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of the Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

C_D	Drag coefficient
C_L	Lift coefficient
C_{DN}	Total drag coefficient in a Newtonian fluid
C_{LN}	Total lift coefficient in a Newtonian fluid
C_{DP}	Pressure component of drag coefficient
C_{DF}	Frictional component of drag coefficient
C_{LP}	Pressure component of lift coefficient
C_{LF}	Frictional component of lift coefficient
D	Diameter of the cylinder (m)
D_e	Deborah number
F_D	Drag force per unit length of the cylinder (N/m)
F_L	Lift force per unit length of the cylinder (N/m)
H	Height (and width) of the square domain (m)
I_2	Second invariant of the rate of deformation tensor (s−2)
L	Length of the cylinder (m)
m	Power-law consistency index (Pa sn)
n	Power-law index
Ni	Number of points on the surface of the cylinder
p	Pressure (Pa)
R	Radius of the cylinder (m)
R_e	Reynolds number
U_x	x-Component of velocity (m/s)
U_y	y-Component of velocity (m/s)
U_0	Uniform velocity of the fluid at the inlet (m/s)
x*	Stream wise co-ordinate, x*=x/R

y*	Transverse co-ordinate, y*=y/R
CFD	computational fluid dynamics
Δ	boundary layer thickness

CHAPTER 1

INTRODUCTION

1.1 Overview

Drone, or *unmmaned aerial vehicles (UAV)* is now been widely used by both the military and civil aviation for operations such as aerial surveying, acrobatic aerial footage filming, search and rescue operation, inspecting power lines and powerlines, counting wildlife, sending medical supplies into remote or inaccessible regions. Although the global forecast for UAV research and development is hardly reliable due to regulation concerns, but many has predicted that the military market to be around $10bn around the year 2024 with the civil market about $3bn at the same time.

As these UAVs typical weighted from 20kg up to 1000kg, they will require a runway to them to take off. However, the time and space required for a runway to be built will be a bottleneck during critical situation such as disaster and war zone, offshore platforms, rural area with mountain terrains. Hence, it is important for these UAVs to have the ability to take off in a short takeoff distance or even vertically, which the lift the aircraft need to be increase significantly.

Lift, is a force component which perpendicular to the in-coming fluid that flow passes a surface of a body, and is most commonly associated with the wing of fixed-wing aircraft which has a special shape called an airfoil. The lift generated thru an airfoil of wing is normally described thru the Bernoulli's Principle where the flows will exert a lower pressure when it speeds up and vice versa as showed in figure 1.1. Throughout the century, intensive researches were conducted on airfoil aerodynamic performance thru mathematical equations, wind tunnel testing and also computational simulation.

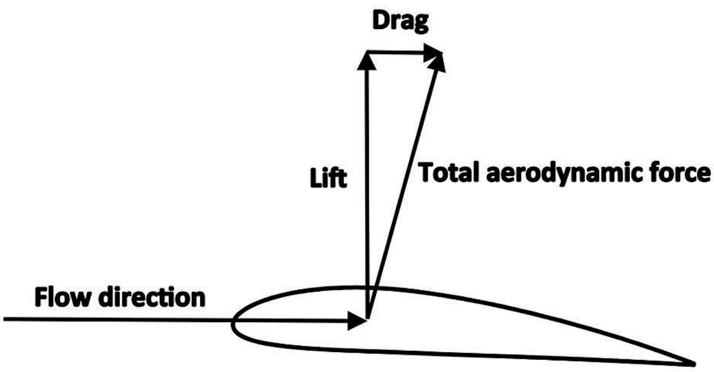

Figure 1.1: Lift Generation on Airfoil

The lift generated thru a airfoil is highly dependent on the incoming air velocity which the UAV will need to have a much more powerful engine to drive the UAVs towards a high speed, which will contributes a much more higher weight of the aircraft. Therefore, other lift generating devices such as the rotating cylinder can be considered as addition to the existing system.

The lift generated by rotating cylinders can also be explained using the Bernoulli Principles. As the cylinder rotates the molecules of air will stick to the surface of the cylinder; this thin layer of molecules will entrain or pull the surrounding flow in the direction that the surface moves. Figure 1.2 indicates that when clockwise rotational movements of a cylinder with the flow moves from left to right, the streamlines around the cylinder are distorted because of the induced flow of the spinning; this contributes to the alternation of the pressure field around the cylinder, and produced an upward force.

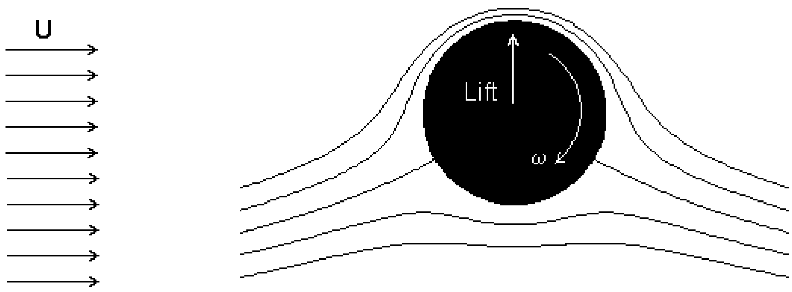

Figure 1.2: Lift Generation in rotating cylinder

Over the decades, researches had focused on optimizing the shape and configuration of the rotating cylinder for a better aerodynamic performance. As the lift generated from rotating cylinder are mainly due to the difference in local velocity due to the spinning behavior of the cylinder, the lift generated can be increased with the decrease in the local velocity at the bottom of the cylinder.

1.2 Problem Statement

As the presence of UAVs for both civil and military operations is getting more and more significant and the market share is expanding, it is necessary to study the possibilities of the usage of rotating cylinder to increase the lift generation during takeoff and landing. The rotating cylinder can be installed behind the airfoil with the device that can increase it spin rate, by increasing the spin rate, we shall be able to increase the lift generated. However, there might be possibilities high vibration when the cylinder is spinning too fast, a flow control device will be required to block the airspeed to lower part of the cylinder so that the good lift generation can be achieve without a high spin rate.

1.3 Objective

The primary objectives of the present work are to:

i. Study the lift generated by the rotating cylinder at typical takeoff speed (~20m/s) with different angular velocity.
ii. Study the effect of upstream square blockage of a rotating cylinder towards the lift generated by the rotating cylinder.

1.4 Scope and Limitations

i. The present work is focused on the lift generation of the rotating cylinder by varying the angular velocity and also placing an upstream blockage as a flow control device.
ii. The typical takeoff speed of UAVs from 20m/s to 28 m/s, the present work will use the a slightly lower speed (11m/s ~ 15m/s) to avoid vibration during wind tunnel experiment.
iii. Wind Tunnel testing is performed without the blockage as a validation to the Computational Fluid Dynamics (CFD) study.
iv. The validated CFD method shall be used to perform the study on different dimension of the upstream square blockage.
v. Drag effect is not included in this study as the main objective is to multiple the lift generated during takeoff and landing.

1.5 Thesis Layout

As such to convey a comprehensive and clear view throughout the subsequent chapters, composing of five chapters, each chapter is briefly described below;

Chapter one offers the background of Unmanned Aerial Vehicle, the current issue that faced by the industry when deploying these vehicles in critical zone and the possibility to develop another lift generation system, which is the rotating cylinder. The challengers and constraints are noticed to be tackle with designed analytical approach to solve state problems and satisfy the objectives of the research.

Chapter two provides an overview of the theory of rotating cylinder, the research and development done on the usage of rotating cylinder in experimental and numerical study.

Chapter three explains the setup in performing the experimental and numerical study. A rotating cylinder was designed, fabricated and installed in the wind tunnel for the testing which follow by numerical study with includes the effect upstream square blockage.

Chapter four offers the results of both the experimental and numerical study with the validation of the numerical studies toward the experimental results. The lift generated for various design of upstream square blockage was discussed in this chapter.

Chapter five delivers a thesis summary and present general research conclusions with recommendation for more detailed and advanced, future work in future.

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