UNIVERSITI PUTRA MALAYSIA

COMPUTATIONAL ANALYSIS OF DOUBLE ROTATING CYLINDERS FOR CONCEPTUAL DESIGN OF AN ESTOL, FIXED WING UAV

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By

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Chairman : Associate Professor Azmin Shakrine Bin Mohd Rafie, PhD
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Many efforts in Unmanned Aerial Vehicle (UAV) aerodynamic design technology led to a broad of additional applications. Magnus effect is the effect of moving airstream to the spinning ball or cylinder**.** Previous studies revealed the feasibility of Magnus effect on rotating cylinder producing lift which impacted an improvement of coefficient of forces. The studies have discovered the limitation of implementation caused by induced and parasite drag occurrences. These challenges addressed in this study to achieve the effect for lifting the body by mean of thinning the boundary layer of the air flow at the upper separation region of rotated cylinder. Accordingly, spin ratio, α and Reynold number, Re are the considerations in this study for optimization. The previous experimental and numerical data were used as a basis to conceptually design of an optimum rotating cylinder aerodynamic characteristics. 2D numerical is simulated using ANSYS FLUENT R15.0 to carefully examine for the coefficient of lift and drag while understanding the aerodynamic characteristics and flow field of the rotating cylinder surface body. Following the methodological approach as the evidences of the Magnus effect, Finite Volume Numerical Analysis method is used in this parametric study. Present work studied on Reynold number, $1 \times 10^3 \leq Re \leq 5 \times 10^5$ and spin ratio ranging from $0 \leq \alpha \leq 4.32$ whereby the air velocity range within 3.65 $ms^{-1} \leq U_\infty \leq 29.208\ ms^{-1}$. Lift Coefficient, C_L and Drag Coefficient, C_D determined in every stage analysis. The optimum C_L based on the parametric study lead to the vital conclusion of concept design of ESTOL UAV fix wing application where the operating cylinders system are embedded inside the NACA airfoil.

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

ANALISIS BERKOMPUTER SILINDER BERPUTAR UNTUK REKABENTUK KONSEP BAGI OPERASI UAV SAYAP TETAP

Oleh

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Banyak usaha dalam teknologi reka bentuk aerodinamik kenderaan udara tanpa pemandu (UAV) membawa kepada aplikasi tambahan yang luas. Kesan Magnus adalah kesan mengalir aliran udara ke bola berputar atau silinder. Kajian terdahulu mendedahkan kemungkinan kesan Magnus pada silinder menghasilkan daya angkat yang memberi kesan kepada penambahbaikan pekali daya. Kajian-kajian telah menemui batasan pelaksanaan yang disebabkan oleh seret teraruh dan seret parasit. Cabaran-cabaran ini ditangani dalam kajian ini untuk mencapai kesan untuk mengangkat badan dengan cara menipis lapisan sempadan aliran udara di kawasan pemisah atas silinder berputar. Oleh itu, nisbah putaran, α dan nombor Reynold, Re adalah pertimbangan dalam kajian ini untuk pengoptimuman. Data percubaan dan berangka terdahulu telah digunakan sebagai asas kepada reka bentuk secara konseptual bagi ciri-ciri aerodinamik silinder berputar yang optimum. 2D berangka disimulasikan menggunakan ANSYS FLUENT R15.0 untuk memeriksa dengan teliti pekali angkat dan seret sambil memahami ciri-ciri aerodinamik dan medan aliran badan permukaan silinder berputar. Berikutan pendekatan metodologi sebagai bukti kesan Magnus, kaedah analisis angka berangka terhingga (Finite Volume Numerical Analysis) digunakan dalam kajian parametrik ini. Oleh itu, kerja semasa yang dikaji pada nombor Reynold, $1 \times 10^3 \leq Re \leq 5 \times 10^5$ dan nisbah spin antara $0 \leq \alpha \leq 4.32$ di mana julat kelajuan udara dalam lingkungan $3.65\ ms^{-1} \leq U\_\infty \leq 29.208\ ms^{-1}$. Pekali Angkat, C_L dan Pekali Seret, C_D telah ditentukan dalam setiap tahap analisis. C_L optimum berdasarkan kajian parametrik membawa kepada kesimpulan penting reka bentuk konsep aplikasi sayap tetap ESTOL UAV di mana sistem silinder operasi dipasang di dalam lelayang NACA.

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LIST OF ABBREVIATIONS

A	aspect ratio
C_L	lift coefficient
C_D	drag coefficient
C_T	torque coefficient
C_P	specific heat capacity
d	cylinder diameter
R	cylinder radius
L	lift
n	Power Law Index
Re	Reynolds number
U_C	airspeed
τ	torque
α	spin ratio
ρ	air density
ω	angular frequency
S	platforms area
q	fluid dynamic pressure
y	distance to the nearest wall
γ	adiabatic coefficient
v	kinematic viscosity
μ	dynamic viscosity,
u*	friction velocity at the nearest wall
C_f	skin friction coefficient
τ_w	wall shear stress
U_τ	frictional velocity
U	inlet velocity

CHAPTER 1

INTRODUCTION

1.1 General Overview

Era of World War 1, the Unmanned Aerial Vehicles (UAVs) or Drones have been developed up to this date and it was and is well proven that the UAVs capabilities to transmit the data to the real-time intelligence in battlefield and processing data information such surveillance and reconnaissance. While the combat type UAVs can perform communication relays, assets neutralized target designation, attacking by its inboard munition as well overviews battle information without risking any aircrew [1]. In 2003, the number of UAV used in military did not give so much impact in terms of quantity. However, it increased rapidly for reconnaissance operation with 32% unmanned aerial vehicles compare to 68% manned aircraft [2].

Irizarry, Javier in his research mentioned that Unmanned Aerial System (UAS) which is the center control of a few UAVs operation can perform tasks similar to those that can be done by manned vehicles, often faster and safer at lower cost. These systems are currently employed in border patrol, search and rescue, damage investigations during or after natural disasters (e.g. hurricanes, earthquakes, and tsunamis), locating forest fires or farmland frost conditions, monitoring criminal activities, mining activities, advertising, scientific surveys, and securing pipelines and offshore oil platforms [3]. This lead to frontline operation activities on utilizing UAVs for most organization and industry to enhance the efficiency, safety and reduce cost. Several countries under the purview of Department of Transportation are implementing the UAV

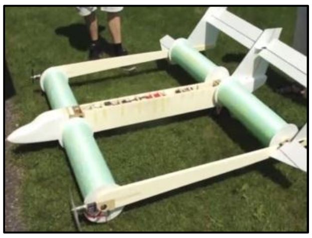
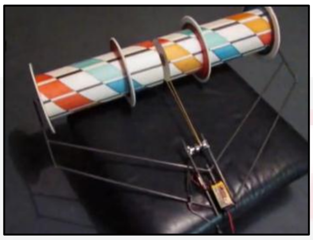
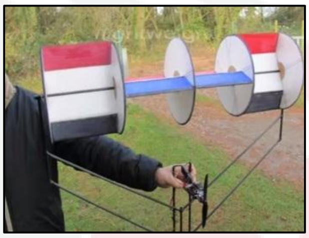
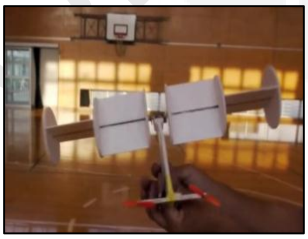
for tracking highway construction projects and performing structure inventories to road maintenance, monitoring roadside environmental conditions as well as many other surveillance, traffic management or safety issues which justify the need of short take off distance UAVs.

Helicopter as its name implies using rotor blades for vertically take off but have low efficiency for cruising in high speed and unable to fly in high altitude. Back in 2006, the Coast Guard acquired Bell Helicopter Textron's_Eagle Eye UAV as part of Deepwater Modernization program [1]. The cost of about 3 million USD, Eagle Eye takes off like a helicopter which is categorized as VTOL, but then tilts up its rotor to fly like a plane. Main task of extending the surveillance capability of cutters, the UAV can fly up to 113.178 ms^{-1} and 482.803 km operate radius. It is capable to patrol the U.S. coastline for drug smugglers, refugees and ships in distress, also transmit video and infrared images to the cutter and command centres ashore but yet costly in this era of economic crisis for most country to be implemented. Furthermore, invented VTOL which is helicopter as an example rotary-wing configuration of interest its auto-gyro, which attempts to dispense with the transmission system of the helicopter in the interest of reducing complexity, but it suffers in that it cannot hover. However, it is able to fly considerably more slowly than can fixed wing aircraft.

UAV now seeks the use of small, unprepared field even no field for the aircraft to take off and landing. Therefore, improvements have been made which concerning a few major factors affecting lift such thrust loading, wing loading and lift coefficient at take-off state that can be concluded as primary components of climb out are the function of thrust to weight ratio and lift-drag ratio. Therefore, the aircraft designed with short field take-off and landing capabilities required to have the ability to fly slowly [2].

The conventional lifting surface of an aircraft, such as the wing of an airplane or the rotor of a helicopter are compulsory to have aerodynamically efficient shape that is called airfoil. An airfoil provides the lifting force when it interacts with a moving airstream or interaction of the airflow about it. The airfoils of some aircraft have more curvature on the top compare to its bottom and it depends on the speed that the aircraft can achieved; however most of the helicopter rotors and many high speed aircrafts use airfoil sections asymmetrically which provide greater pressure and velocity gradient. The movement of the air stream around the airfoil causes changes in the surrounding air pressure distribution to create lift. Another potential lift generator is Magnus effect of spinning cylinder with constant rotational rate while a turbulent flow moved through it [3]. It had been proven by several inventions of Magnus rotor wing aircraft in early 1920s but the developments has stopped in 1928 due to high cost [4]. However, researchers continues to develop fan wing aircraft which increase the lift coefficient but have difficulties of maneuvering in low speed and caused hard landing [5][6]. In 2012 to 2014, inventors have designed small sized aircraft named as rotor wing aircraft which used the concept of Magnus rotor wing in order to prove the flight feasibility by using the Magnus effect principle and the result were promising for take-off even landing in short distance (refer to Table 1.1), it can be concluded that there is still a gap of research to explained the used of spinning cylinder as good lift generator. The lacking can be recognized based on Table 1.1 is the designs were not suitable for high altitude, high cruising speed, high endurance and stability.

Table 1.1 : Rotor Wing - Rotating Cylinder development activity from 2012 to 2014

Year	Aircraft	Flight Prove / Result	Descriptions
2012			Flettner – Rotoren Specification : 1. Propeller driven 2. No flight control 3. Conventional airframe
2013			Rotorwing Flettner Monowing Specification : 1. Universal joint motor-propeller 2. No flight control 3. Y-frame
2013			Rotorwing Biconvex Savonius Specification : 1. Universal joint motor-propeller 2. No flight control 3. Y-frame
2013			Spinning Cylinder Wing (Rotor Wing - RC) Specification : 1. Propeller driven 2. With flight control 3. Conventional airframe
2014			Magnus effect plane - Rotorwing Specification : 1. Twin propeller driven 2. No flight control 3. Conventional airframe

(Adapted from www.youtube.com)

The research on rotating cylinder benefitted in many industries even country for the effect caused by the cylinder rotation through fluid, at specific spinning velocities with suitable Reynolds number, Re whereby achieving broader insight to maneuverability controllability and stability in lateral motion and longitudinal control for submarines and ships. As an inference, the rate of lifting is nearly independent due to angle of attack and angle of incidence, UAV maneuverability, controllability and stability which using rotating cylinder can be manipulated by the study of angular velocity, ω as well the involvement Reynold number, Re. In this work, the limitation of the current Magnus effect concept aircraft flight operation can be improved by analyses the optimum parameters focusing on incompressible airflow within suitable Reynolds number, Re, spin ratio, α and rotating cylinder speed. Therefore, the important of the gap in knowledge is the enhancement of the aerodynamic characteristic aligned with the needs of the UAVs to be able to operate for front-liner consumers. Therefore, the optimum parameters and significant variables which are in great concern is needed to be studied for improve current UAV operation to meet desired economical, efficient and safety compare to previous works and conventional type airfoils.

1.2 Problem Statement

Helicopter considered full prove for vertical take-off and landing operation however gave several disadvantages on its mechanical design simplicity, noise emission, stall potential whenever speed is concerned, lower cruising speed, unsafe for high altitude manure for power back operation and costly for production and maintenance [7]. UAV's are designed with conventional airfoil section by its any surfaces to provide aerodynamic force when it interacts with a moving stream of air. Front-line UAV users currently demands on small airport, unprepared field or even un-field for having the technology [2]. Previous researchers had discovered the potential of S/VTOL for flight operation by introducing Magnus effect as lifting device. However, the technology limited with lower efficiency than existing propulsions and still at early stage [6]. Therefore, this work intended to fill the research gap by parametrically studied on the variables involve such as Reynolds number and spin ratio as well the effect of cylinder size, free air flow and focus air flow in order to suit and improve UAVs fixed wing application take-off and landing operation namely Extreme Short Take-Off / Landing (ESTOL) by using rotating cylinder as a main lifting devices and limited to fixed wing UAV.

1.3 Research Objectives

The objectives of this study is to assess practicality of using rotating cylinder for lifting purpose. Therefore a number of objectives need to be addressed which presented in the following:

1. To specify the design requirements for an ESTOL fixed wing UAV using rotating cylinders.
2. To parametrically investigate the variables affecting the performance of rotating cylinders.
3. To analyze the performance of the proposed design of double rotating cylinder for ESTOL fixed wing UAV.

1.4 Scope of Study

Study on the practicality in this research begins with the coefficient of forces either lift or drag created by Magnus effect using rotating cylinder with incompressible condition air velocity flown through the cylinder body. The key for achieving this are within the use of Reynold number, Re = 2.2 x 10^4, spin ratio, α = 1.54, rotational speed, U_θ = 718.67 $rads^{-1}$ and the air velocity, U_∞ = 7 ms^{-1} where the air ideal gas at 1 ATM pressure with 15° temperature constitutes following properties with specific heat, C_P of 1.005 x 10^3 $JKg^{-1}K^{-1}$, adiabatic coefficient, γ of 1.404, Prandtl number of 0.717, kinematic viscosity, ν of 1.466 x 10^{-5} $kgm^{-1}s^{-1}$ and Dynamic Viscosity, μ of 1.789 x 10^{-5} $kgm^{-1}s^{-1}$ and air density, ρ of 1.225 kgm^{-3} are defined at constant in this work. NACA16015 is considered have the advantages such as high pressure peaks with low drag at high speed but relatively low lift and relevant constant to carry out this study.

The models validations were carried out by 2D numerical simulation using ANSYS FLUENT R15.0 and analyzed for the highest and lowest coefficient of lift produced throughout the significant variables using SPSS. Optimization of coefficient of forces were carried out numerically by several approaches on the effect of cylinder size as the concept will introduced a small scale cylinder size compared to experimental, free air flow where a wall block functioned as air flow restrictor for the rotated cylinder and focus flow whereby the air velocity flown focused closely to the rotated cylinder. Several potential configurations for enhancing approaches were identified which resulted the concept design of two rotating cylinders system inside airfoil.

1.5 Thesis Outline

Chapter 1 of the study begin with the general overviewing the aerodynamic characteristic for current UAV development. The overviews narrowed to the need of front line UAV users for short/vertical takeoff and landing. Magnus effect of rotating or spinning cylinder is an alternative to improve lift force. This chapter comprises with problem statement, research objectives and scope of study.

Chapter 2 presents a comprehensive literature review, starting with Airfoil Aerodynamic Characteristics and Configuration for aerospace and aeronautic application, Unmanned Aerial Vehicles (UAVs) developments, current technology and method for Short / Vertical Take Off and Landing (STOL/VTOL) aircraft, Magnus effect together with supported Kutta-Joukowski Lift Theorem. The need of popular tool for numerical analysis is also discussed in this chapter.

Chapter 3 is the methodological approach for this study on the evidences of the effect of rotating cylinder as lifting device. In this chapter, a process flow chart for this work is introduced. Besides that, a few significant parameters and variables are crucially studied whereby numerical model of validations and several approaches are important in order to optimize and enhance the result. Therefore, a step of developing the work is revealed in such way explaining the procedure and parametric study of carrying out the research to meet the objectives.

Chapter 4 is the discussion on the obtained results. In this chapter, the initial discussion as to compare between previous work and present work carried out numerically. Results gained due the effect of several approaches carried in order to optimize the coefficient of forces. Furthermore, the final approaches as well the concept design of ESTOL for UAV fixed wing application also being discussed in this chapter.

Chapter 5 provides the conclusion of this study by discussing the outcome of the research. Results gained in chapter 4 are summarized with further explanations for concluding this work. A conceptual design has been designed for meeting the objectives. Finally, a few of recommendations and improvements were suggested as a basis for future studies.

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