CFD STUDY OF A MICRO AIR VEHICLE (MAV)

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A report is submitted
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DECLARATION

I declare that this project report entitled "CFD Study of a Micro Air Vehicle (MAV)" is the result of my own work except as cited in the references.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Supervisor's Name : Fatimah Al-Zahrah Mohd Sa'at

Date : 17/7/2021

ABSTRACT

Micro Air Vehicles (MAV) are new type of aircraft maturing day by day and have reached unprecedented levels of growth recently. MAV is actually small kind of Unmanned Air Vehicle (UAV), MAV also have enormous potential in applications, both military and civilian. There are three types of MAV, namely rotary wing, flapping wing and fixed wing. All of them exist nowadays and each of them contain specific capabilities and limitations. As MAV is small in size, MAV is hard to have a proper flight as they have to face the sensitivity issues due to the atmospheric perturbations. This study aims to model a suitable fixed wing MAV, using ANSYS CFD to simulate the lift coefficient, drag coefficient and lift to drag ratio to validate the simulation results with previous research and proceed it with parametric investigation. As considering the MAV is operating under an actual condition where cruise with wind disturbance, parametric investigation is carried out to determine the impact on lift coefficient and drag coefficient. The simulation results show that there would be impact on the lift coefficient and drag coefficient for several angle of attack, however, the lift to drag ratio is yet to be affected. In addition, this fixed wing MAV model would operate and had the best performance at 8° angle of attack as it obtained the maximum lift to drag ratio for both situations without and with the present of wind disturbance. Besides, the fluid dynamics behavior of flow around MAV at several angle of attack was observed and discussed accordingly. Even though MAV is small in size, it is found that vortex or vorticity flow also exist in MAV, especially at high degree angle of attack. Hence, the angle of attack is an important factor that should take into consideration for designing MAV.

ABSTRAK

Micro Air Vehicles (MAV) adalah jenis pesawat baru yang matang dari hari ke hari dan telah mencapai tahap pertumbuhan baru-baru ini. MAV sebenarnya adalah jenis Unmanned Air Vehicle (UAV) yang kecil, MAV juga memiliki potensi besar dalam aplikasi, terutamanya dalam aplikasi ketenteraan. Terdapat tiga jenis MAV, iaitu sayap berputar, sayap mengepak dan sayap tetap. Kesemuanya wujud pada masa kini dan mengandungi kemampuan dan had tertentu. Oleh kerana MAV berukuran kecil, MAV sukar untuk memiliki penerbangan yang tepat kerana mereka harus menghadapi masalah kepekaan akibat gangguan atmosfera. Kajian ini bertujuan untuk memodelkan MAV sayap tetap yang sesuai, menggunakan ANSYS CFD untuk mensimulasikan pekali angkat, pekali seret dan nisbah angkat ke seret untuk mengesahkan hasil simulasi dengan penyelidikan sebelumnya dan meneruskannya dengan penyelidikan parametrik. Memandangkan MAV beroperasi dalam persekitaran sebenarnya di mana pelayaran dengan gangguan angin, penyelidikan parametrik dilakukan untuk menentukan kesan pada pekali angkat dan pekali seret. Hasil simulasi menunjukkan bahawa terdapat pengaruh pada pekali angkat dan pekali seret untuk beberapa sudut serangan, namun, nisbah angkat ke seret tidak terpengaruh degan ketera. Selain itu, model MAV sayap tetap ini dapat beroperasi dan mempunyai prestasi terbaik pada sudut serangan 8° kerana memperoleh nisbah angkat ke seret maksimum untuk kedua-dua situasi, iaitu tanpa dan dengan adanya gangguan angin. Selain itu, perilaku dinamik bendalir aliran sekitar MAV pada beberapa sudut serangan diperhatikan dan dibincangkan dengan sewajarnya. Walaupun ukuran MAV kecil, didapati aliran vorteks atau pusaran juga terdapat pada MAV, terutama pada sudut serangan tahap tinggi. Oleh itu, sudut serangan adalah faktor penting yang harus dipertimbangkan untuk reka bentuk MAV.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
MAV	Micro Air Vehicle
DARPA	Defense Advanced Research Projects Agency
UAV	Unmanned Air Vehicle
μUAV	Micro Unmanned Air Vehicle
NAV	Nano Air Vehicle
PAV	Pico Air Vehicle
SD	Smart Dust
DC	Direct current
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IMU	Inertial Measurement Unit
LiPo	Lithium Polymer
RF module	Radio Frequency module
LSB	Laminar Separation Bubbles
AR	Aspect Ratio
GPS	Global Positioning System
CPU	Central Processing Unit
RG	Rolf Girsberger

NACA	National Advisory Committee for Aeronautics
SAS	Scale-Adaptive Simulation
URANS	Modified Unsteady Reynolds Average Navier-Strokes
CSIR	Council of Scientific and Industrial Research
NAL	National Aerospace Laboratories
LLT	Lifting Line Theory
VLM	Vortex Lattice Method
3D	Three Dimensional
CAD	Computer Aided Design
LAR	Low Aspect Ratio
MIZ	Modified Inverse Zimmerman
MIC	Mean Aerodynamic Chord

LIST OF SYMBOLS

C_L	=	Lift coefficient
C_D	=	Drag coefficient
L/D	=	Lift to drag ratio
AOA	=	Angle of attack
Re	=	Reynolds number
M	=	Mach number
F_l	=	Lift force
F_D	=	Drag force
ρ	=	Air density
v	=	Relative velocity
T_{SL}	=	Thrust at sea level
W_{TO}, W	=	Weight
S	=	Aircraft area
α	=	Ratio of momentarily thrust and sea level thrust
β	=	Ratio of momentarily weight
q	=	Dynamic pressure
V	=	Flight speed
h	=	Flight height

g	=	Gravitational acceleration
C_{D0}	=	Zero drag coefficient
C_{Lmax}	=	Maximum lift coefficient
e	=	Oswald efficiency number
U	=	Free stream velocity
c	=	Airfoil chord length
v	=	Fluid kinematic viscosity
f	=	Frequency of oscillation
L	=	Streamwise length of MAV

CHAPTER 1

INTRODUCTION

1.1 Background

Micro air vehicles (MAV) are a relatively new and undergo rapidly growing area of aerospace research. Researches had been carried out in the countries such as Unites States, Japan and China in the 19 century. According to Michelson (2006), an American nonprofit institution, RAND Corporation, that helps in improving policy and making decision through research and analysis, found out the MAV feasibility study in 1994 and concluded that MAV had great potential for military applications. MAV were first defined by the US Defense Advanced Research Projects Agency (DARPA) in 1997 as unmanned aircraft that are less than 15 centimeters or 6 inches in any dimension (Petricca et al., 2011). Nowadays, the target dimension and development of insect-sized aircrafts is reportedly expected in the near future.

Furthermore, Micro Air Vehicles (MAV) are actually small kind of unmanned air vehicles (UAV) which are used for surveillance, reconnaissance, armed attacking, search and rescue operations, transportation and scientific research. MAV can be remotely or autonomously controlled, without a human operator on board. Basically, MAV are smaller in size and weight compared to UAV. Because of its smaller size, the probability of MAV being intercept by radar is low and therefore, they are manufactured for several missions. They can reach a maximum travel speed of 20 m/s and capable on day and night usage (Kurtulus, 2019). Thus, they are very suitable for military surveillance applications and image recording. Besides, MAV also produce lower noise when functioning and have lower production cost compared to the UAV. In addition, MAV can be operating at Reynolds numbers up to 200000, depending on the size and types of MAV.

Next, MAV also being used in urban applications to monitor the traffic flow and mapping areas. MAV can also be used to observe the weather condition and provide real time tracking of current location with the installation of gradient sensors and flight control feedback which provide the weather updates from time to time to the community. Nowadays, MAVs have developed with great improvements in designs with advances of computer aided technology, power supply with better battery technology, and visual communications with better transmitters and receivers. There are various types of MAV such as rotary wing, flapping wing and fixed wing. They are all now in existence and each of them contain specific capabilities and limitations.

Figure 1.1: Sample of rotary wing MAV (Ward et al., 2017)

Rotary wing MAVs as shown in Figure 1.1, are basically functionally similar with the concept of helicopters, the lift and thrust are generated by spinning of rotor blades. The surface area of rotors would determine the magnitude of aerodynamic forces supply. When the rotors are spinning in opposite directions with a balanced manner, the rotary wing MAV can be easily stabilized and the rotation of downwash air will be minimized (Ward et al., 2017). Thus, the movement can be easily control and pilot by users. In addition, the generation of both lift and thrust could also be increase by using multiple sets of rotors such as quadrotors.

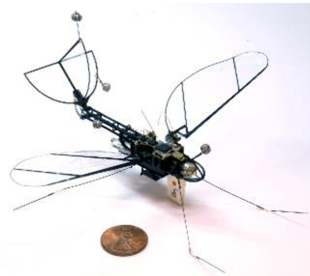

Figure 1.2: Sample of flapping wing MAV (Ward et al., 2017)

Next, the flapping wing MAVs which also known as biomimetic MAVs are bioinspired with the ideas from the flapping wings of insects and birds, a sample is as shown in Figure 1.2. Flapping wing MAV is relatively smallest in size compared to the others and it is more suitable for indoor applications which able to fly through narrow gap. It is more complex and complicated to build up as it consists of light weight structures and small scale electronics device. Lift and thrust are achieved by flapping the wings and the corresponding flapping frequency depends on the surface area of wings (Ward et al., 2017).

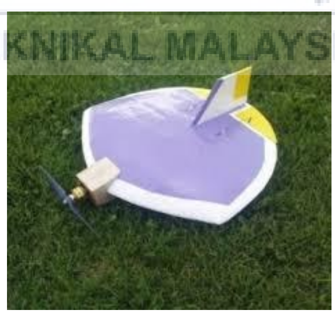

Figure 1.3: Sample of fixed wing MAV (Ward et al., 2017)

On the other hand, Figure 1.3 above shown a sample of fixed wing MAV, which are not really suitable for indoor usage whereas more suitable for outdoor surveillance missions since they have higher payload and endurance capabilities compare to the rotary and flapping wing

MAV of equal size (Ward et al., 2017). A propeller-driven electrical motor is normally used in fixed wing MAV to produce thrust. Lift is generated by air flowing over the non-moving wings of airfoil cross sections. Fixed wing MAVs are more difficult to achieve good performances at low speed flight as its wings are associated with stringent dimension constraints which requires high cruise speeds.

1.2 Problem Statement

According to Kunz (2003), the most common problem that is faced by the micro air vehicle, MAV is having a low Reynolds number which due to its small size. Previous research indicates that there will be an increase in maximum lift coefficient with a decreasing in Reynolds number. However, as the Reynolds number decreases, the lift to drag, L/D ratio also decreases. This is because the power required to operate the flight is a more restrictive consideration than providing the lift force. Hence, flight at these Reynolds numbers is much less efficient than at higher Reynolds numbers. It is important to operate the airfoil at its maximum lift to drag ratio for its optimum performance. Besides, the limitation of power supplied for these MAV at such small scales is also technological factor nowadays.

Flow at low Reynolds numbers is dominated by viscosity, and as the Reynolds number is reduced, the effects of increasing boundary layer thickness become more significant (Kunz, 2003). These leads in effect of higher drag condition. Thus, low Reynolds numbers affect the aerodynamic efficiency and the propulsion efficiency dramatically. These problem causes that the MAVs hard to have a proper flight as they have to face the sensitivity issues due to the atmospheric perturbations. Therefore, the lift coefficient, drag coefficient and the fluid dynamics around the MAV are important aspects to be investigate so that the MAV could be functioning under optimize condition.

1.3 Objectives

The objectives of this project are:

1. To model a suitable MAV using ANSYS CFD.
2. To determine the impact of lift coefficient and drag coefficient of operating MAV.
3. To evaluate the fluid dynamics behavior of flow around MAV.

1.4 Scope of Project

The scopes of this project are:

1. The flow is computed by commercial software ANSYS CFD Fluent.
2. The simulated result is only based on fixed wing micro air vehicle.
3. The investigation is focused on MAV with flight velocity of 12 m/s.
4. The fluid dynamics behavior of flow to be probe is only outside the platform of MAV model.

CHAPTER 2

LITERATURE REVIEW

2.1 Small Size Air Vehicle

Automation and remote technology have been present for centuries, these increases the capability of individual operations and capacity of the system to carry out task functionality by human. Drones are literally used as war appliance which leads victory to expand their territory in World Wars 1 and 2. For examples, airborne drones were used to disrupt airspace, drop ordinance on enemy territory and also acts as target practice for pilots. By history of drones, they are most commonly used in military deployment. On the other hand, widespread and increasing usage of drone in non-military roles are also acquires consideration nowadays (Hodgkinson and Johnston, 2018).

Besides, drone could also provide live stream, real time video, image capture along the flight and also transport good. From aspects of railways, occasionally they used drone locomotives instead of driver occupied locomotives to make human work life more comfort. The use of drones in commercial application is growing and their deployment in remote work will leads to cost reduction and capability enhancements in certain field such as transporting and agricultural scanning. The technology is still in development phase, the significant potential versatility drones may provide and leads to the achievement of new social, business, and logistics services in future (Atwater, 2015). Although it may expand the usage in future as the technology getting more advance, it may also bring and create a potentially disruptive scenario by causing problems to the current economic system.