PROPELLER LOCATIONS STUDY ON DELTA-WINGED UNMANNED AERIAL VEHICLE (UAV) MODEL

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Specially dedicated to my supportive and lovely parents,

siblings and friends for always being at my side.

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ABSTRACT

Delta wing design is being used in aircraft to obtain high manoeuvre properties. The flow above the delta wing is complicated and dominated by a very complex vortex structure. This research investigates the effects of the propeller locations on the aerodynamic characteristics above a generic 55° sharp-edged non-slender delta wing Unmanned Aerial Vehicle (UAV) model. This research was performed by an experimental method. The experiments were conducted in a closed circuit Universiti Teknologi Malaysia-Low Speed Tunnel (UTM-LST) wind tunnel at wind speed of 20 m/s and 25 m/s respectively. In this project, the propeller was located at three different locations at front, middle and rear of the wing. The experimental data highlights an impact of propeller locations on lift, drag, pitching moment and vortex characteristic of the UAV model. Rear propeller configuration recorded the highest lift generation. Meanwhile, middle propeller configuration has the highest drag with increment by 2% to 15%. The results also show that the propeller advance ratio plays important roles in development of the primary vortex above the delta-winged model. The higher propeller advance ratio would decrease the development of the vortex on the wing, consequently limiting the lift generation and stall condition in which are disadvantageous for aircraft aerodynamic characteristics. The lift coefficients decrease by 7% when the propeller advance ratio is increased from 0.98 to 1.20. Lastly, suction effect from the propeller has improved the vortex properties better than blowing mechanism in which is beneficial for the delta-winged UAV propeller selection.

ABSTRAK

Penggunaan reka bentuk sayap delta diaplikasikan pada pesawat bagi memperoleh olah gerak yang tinggi. Penggunaan sayap delta ini dapat dimanfaatkan dengan penghasilan daya angkatan yang lebih baik berbanding dengan reka bentuk pesawat konvensional. Walau bagaimanapun, aliran udara di atas permukaan sayap delta ini sangat kompleks kerana reka bentuk ini mempunyai aliran pusaran yang terhasil di sisi sayap. Oleh itu, kajian ini dibuat bagi mengenal pasti kesan lokasi kipas yang diletakkan pada model Pesawat Udara Tanpa Pemandu (UAV) dari segi aspek aerodinamik dan corak perubahan aliran pusaran di atas permukaan sayap delta. Model UAV yang digunakan dalam kajian ini merupakan sayap delta 55° bersisi tajam. Kajian dijalankan secara eksperimen menggunakan terowong angin litar tertutup Universiti Teknologi Malaysia-Low Speed Tunnel (UTM-LST) pada kelajuan angin 20 m/s dan 25 m/s. Posisi kipas diletakkan di tiga tempat berbeza iaitu di hadapan, tengah dan belakang model. Hasil dapatan kajian difokuskan terhadap kesan lokasi kipas terhadap daya angkatan, daya heretan, momen anggulan dan ciri vorteks. Data daripada eksperimen mendapati pemasangan kipas terhadap model UAV mempengaruhi daya angkatan, daya heretan dan momen anggulan model pesawat. Kipas yang dipasang di belakang model mencatatkan nilai pekali daya angkat yang tertinggi. Manakala kipas yang dipasang di tengah model mencatatkan daya heretan yang tertinggi dengan peningkatan sebanyak 2% hingga 15%. Hasil dapatan kajian juga menunjukkan bahawa nisbah mara kipas memainkan peranan penting dalam pembentukan aliran pusaran di atas sayap delta. Nisbah mara kipas yang tinggi akan mengurangkan pembentukan aliran pusaran di atas sayap delta sekaligus mengehadkan penghasilan daya angkatan dan pendakian pesawat. Pekali daya angkat didapati berkurangan sebanyak 7% apabila nisbah mara kipas dinaikkan dari 0.98 ke 1.20. Akhir sekali, kesan penggunaan kipas terhadap aliran pusaran menunjukkan bahawa mekanisme sedutan memberikan kesan yang lebih ketara berbanding dengan mekanisme tiupan.

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c	-	Mean aerodynamic chord
C	-	Wind tunnel cross sectional area
C_D	-	Drag force coefficient
C_L	-	Lift force coefficient
C_M	-	Pitching moment coefficient
C_P	-	Pressure coefficient
D	-	Propeller diameter
f	-	Propeller frequency
F	-	Force
J	-	Propeller advance ratio
L	-	Spanwise length
L/D	-	Lift to drag ratio
M	-	Moment
P	-	Pressure
q	-	Dynamic pressure
Re	-	Reynolds number
S	-	Surface area
T	-	Temperature
v	-	Velocity
V	-	Volume

Y/Cr	-	Chordwise location
Λ	-	Wing sweep angle
α	-	Angle of attack
β	-	Prandtl-Glauert compressibility factor
ε	-	Blockage component
μ	-	Dynamic viscosity
ζ	-	Angle between wing surface with vortex core
ρ	-	Air density
τ	-	Solid-blockage constant

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Unmanned Aerial Vehicle (UAV) is an aerial vehicle that operates without a pilot on board. UAVs can be operated by the pilot at the ground control station (controlled aircraft) or autonomous flying by preprogramed flight routes (autopilot system). There are numerous types of UAVs available with various shapes and sizes. UAVs exist in many types with different capabilities for the user requirements (Bento, 2008). Development of UAV was instigated by the piloted aircrafts evaluations (Koma et al., 2008). The primary advantage of the UAV over piloted aircraft is portability. UAV is easily to be stored, transported and launched in time-sensitive manner. Thus, this made the operational cost of UAVs are cheaper compared to conventional aircraft. UAVs can overcome the limitations of piloted aircraft such that unnecessary risk exposure towards pilots and air crews during rescue missions or surveillance operations. As UAVs are operated remotely, rescue and surveillance activities in dangerous and non-accessible area can be performed without risking more lives (Tajima et al., 2013; Nakashima et al., 2014). Aircraft with smaller design is becoming essential to be used for limited period missions for both military and civil purposes (Koma et al., 2008). Development of battery, wireless and Micro-Electromechanical Systems (MEMS) have enable UAVs with increased capability at lower cost and smaller in size (Hall et al., 2009). The current smallest UAV is Robo-fly shown in Figure 1.1 is having insect imitation (entomopters) only weighing 106mg and capable of search and rescue missions (Griffiths, 2014). UAVs becoming more favourable as its special capability to operate lower than crewed aircraft. Furthermore, UAVs are capable to achieve a higher elevation than any land vehicles. The usage of UAVs can be seen in 1940 when 15,000 units of radio controlled target drones were sold to United States military for anti-aircraft training for World War II by Reginald Danny (Dillow, 2014). Currently, large and small companies are developing and designing UAVs (Shafer & Green, 2010). Large companies conducting research on the UAVs design by using computational fluid dynamics (CFD) and wind tunnel testing, enabling them to have better potential design before flight testing.

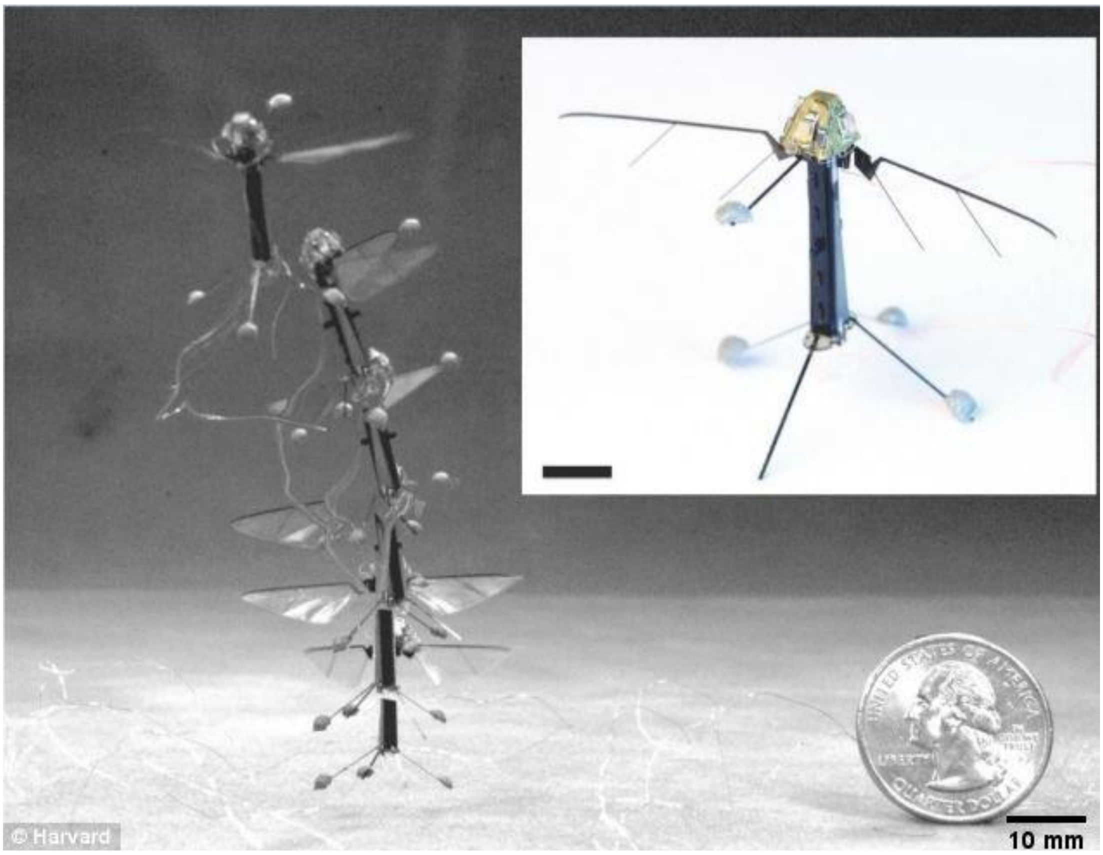

Figure 1.1: Robo-fly UAV (Griffiths, 2014)

Numerous different groups have suggested reference standards for UAVs. One of them is the European Association of Unmanned Vehicle Systems (EUROVS). The EUROVS had classified UAVs based on several parameters such flight endurance, altitude and size (Bento, 2008). Table 1.1 shows the classification of UAVs created by EUROVS.

Table 1.1: Classification of UAVs by EUROVS (Bento, 2008)

	Category (acronym)	**Maximum Take Off Weight (kg)**	**Maximum Flight Altitude (m)**	**Endurance (hours)**	**Data Link Range (km)**
Micro/ Mini UAVs	Micro (MAV)	0.10	250	1	<10
	Mini	<30	150-300	<2	<10
Tactical UAVs	Close Range (CR)	150	3,000	2-4	10-30
	Short Range (SR)	200	3,000	3-6	30-70
	Medium Range (MR)	150-500	3,000-5,000	6-10	70-200
	Long Range (LR)	-	5,000	6-13	200-500
	Endurance (ER)	500-1,500	5,000-8,000	12-24	>500
	Medium Altitude, Long Endurance (MALE)	1,000-1,500	5,000-8,000	24-48	>500
Strategic UAVs	High Altitude, Long Endurance (HALE)	2,500-12,500	15,000-20,000	24-48	>2,000
Special Task UAVs	Lethal (LET)	250	3,000-4,000	3-4	300
	Decoys (DEC)	250	50-5,000	<4	0-500
	Stratospheric (Strato)	TBD	20,000-30,000	>48	>2,000
	Exo-stratospheric (EXO)	TBD	>30,000	TBD	TBD

In the past, UAVs had been used mostly for the military purposes. Currently, UAVs is starting to be used in scientific, commercial and public safety tasks (Bento, 2008). UAVs purpose to carry out civil missions' potential was discovered when UAVNET (UAV Network) project is launched in October 2001. This is followed by another two projects, USICO (UAV Safety Issues for Civil Operation) and CAPECON (Civil UAV Applications and Economic Effectivity and Potential Configuration Solutions) in May 2012 (Smith & Rajendran, 2014). Dillow (2014) stated the usage of UAVs for non-military purposes have been escalating in developed countries such as

Japan, France, United Kingdom and Australia. UAVs are a potential device to be used in various applications such as in agriculture, map building, traffic surveillance, construction, film production, search and rescue mission and weather forecasting. For the meteorology field, UAV is used to observe development of storms (Handwerk, 2013). From the program, the valuable surveillance in stormy area can be captured by the UAV which cannot be performed by the manned plane. In topography field, Sensefly and Drone Adventures promotes usage of UAV for civil application by mapping Matterhorn mountain, which is located on the border between Switzerland and Italy (Carrol, 2013). For agriculture purposed, UAV cameras can be used to monitor growth of plants at specific field section. Current UAV is equipped with infrared camera enabling plant health observation based on the photosynthesis efficiency (Handwerk, 2013). One of the flying UAV used for civil application is LA100 which is shown in Figure 1.2. LA100 is produced by Lehmann Aviation Ltd and having 92 cm wingspan and 1.25 kg in weight. LA100 is designed for civil applications such as reconnaissance, security, mapping, survey and monitoring. The UAVs are able to take still aerial images and real-time videos.

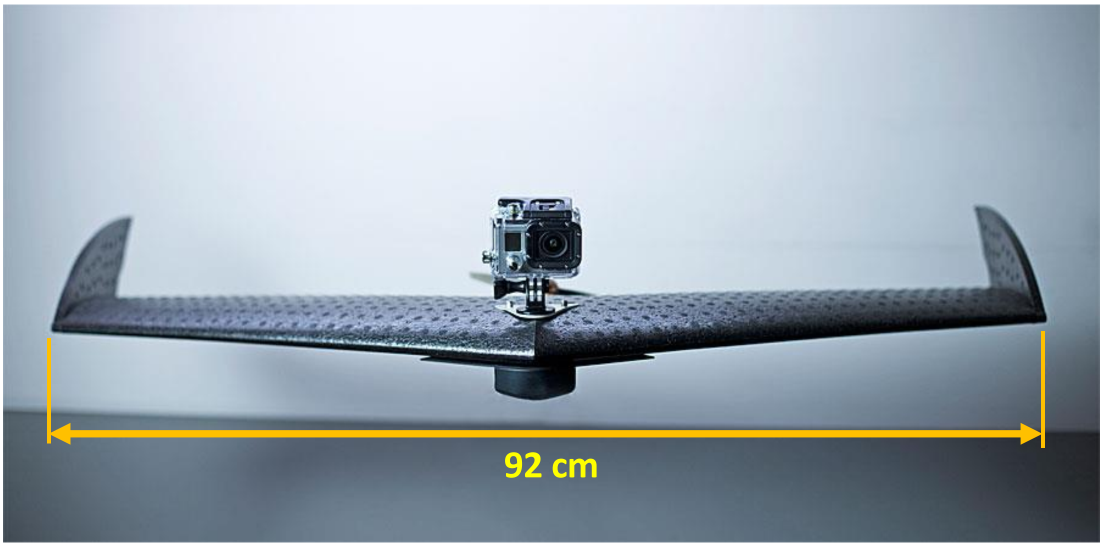

Figure 1.2: LA100 UAV (Lehmann Aviation, 2014)

1.2 Delta-Winged UAV

The advancement of the technology has triggered essential of aircraft that capable of higher speed and manoeuvre. Delta wing configurations are suitable for both supersonic and subsonic aircraft (Pevitt & Alam, 2014). The delta wing design initially was carried out in Germany in the early 1940s (Whitford, 1987). After the Allied won the Second World War, delta wing design was appeared on drawing for major aircraft design. The delta wing is having triangle appearance on wing plan and is named after Greek letter delta (Δ) as their similar shape (Teli et al., 2014). The delta wing configuration can be divided into slender and non-slender wing based on their swept angle (Λ). Slender wing having very high swept angle which are Λ>60°. Delta wing is categorised in fixed-wing UAVs alongside with flying wing class and blended winged body (BWB) class. There is different type of delta wings, which are standard delta, tailed delta, cropped delta, compound delta, cranked arrow, ogival delta, lambda delta and diamond wing. The delta wing configurations are shown in Figure 1.3.

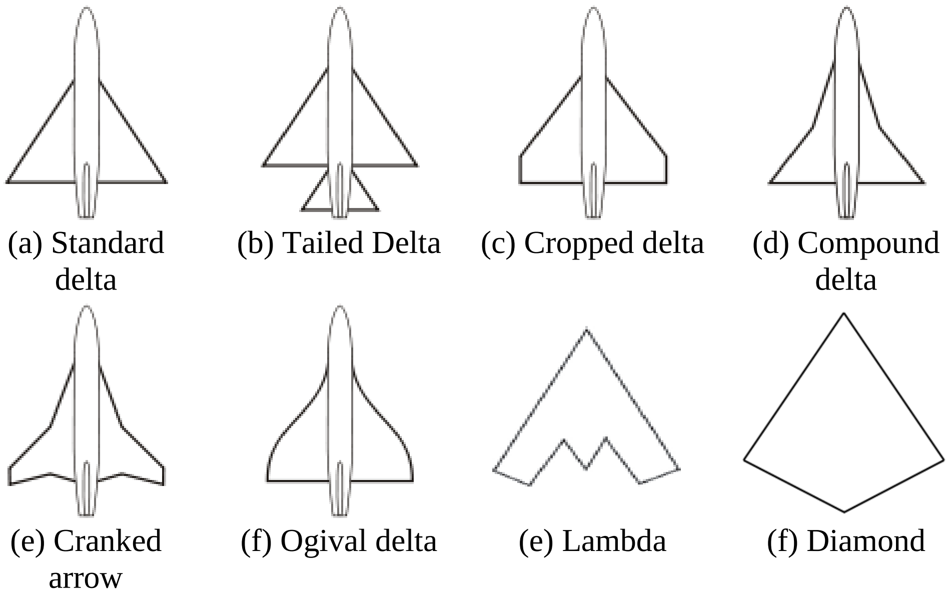

Figure 1.3: Delta wing configurations (Pevitt & Alam, 2014)

Currently, delta wing design is implanted in UAVs application (Tricoche et al., 2004). Delta planform is favourable in the UAVs design because of the excellent properties at a higher angle of attack (Polhamus, 1966). Delta wing configuration in UAV shows aerodynamic advantages over conventional design in power efficiency and lower ratio of wetted area to volume (Tajima et al., 2013). Delta-winged UAV design is always simple and robust. Thus, the delta wing aircraft is having less complex design and having high durable design accompanied by extra internal volume for power source and aircraft system. Normally, delta wing UAV is stronger than a similar swept wing UAV. The delta winged UAV can be built stronger than swept wing aircraft as the spar attaches with the fuselage afar in front of the centre of gravity. Since delta wing aircraft having simple design, it is likely to have less impact during crash and could minimise the possible damage that may occur. The manufacturing cost of the delta wing could be reduced as it need less materials. Figure 1.4 shows several existing flying delta wing UAVs.

Figure 1.4: Several examples of delta winged UAVs (RCGroups.com, 2014; SkyHighHobby.com, n.d.)

1.3 Research Objective

The aim of this project is to investigate the effects of propeller locations on the aerodynamic and vortex characteristics above sharp-edged delta wing UAV. In order to achieve the said objectives, the research will;

(i) Measure the aerodynamic characteristics of delta-winged UAV with and without rotating propeller.
(ii) Investigate the effects of propeller locations on the vortex characteristics of the delta-winged UAV model.
(iii) Investigate the effects of advance ratio for all propeller configurations on the delta-winged UAV.

1.5 Scope of the Research

As the main objective of this project is to investigate the effects of propeller locations on the vortex properties above non-slender sharped-edge delta wing, the scopes of this research are divided into four stages:

(i) Literature review on delta wing UAV and delta wing flow topology.
(ii) Model design and fabrication of the UAV model in standard delta category.
(iii) Wind tunnel experiment of the model without the propeller, called as clean wing configuration.
(iv) Wind tunnel experiment of the model with several propeller locations. In this project, the locations of the propeller were set at three stations:
    - In front of the wing.
    - In the middle part of the wing.
    - In the rear part of the wing.

It has been decided that the motor speed was set at 6,000 rpm since most of the UAVs are flying at this speed.

1.6 Significance of the Research

This research would provide a better insight into the aerodynamic characteristic and the vortex properties above delta-winged UAV under the effects of rotating propeller installed on the wing at three locations, i.e. front, middle and rear. The speed of the motor was set at 6,000 rpm based on the standard range of propeller speed in the same category of UAV. Two measurements techniques which are steady balance data and surface pressure measurement are used to evaluate the UAV performance.

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