Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Aerodynamic Characteristics of Tube-Launched Tandem Wing Unmanned Aerial Vehicle

To cite this article: Nurhayyan H. Rosid *et al* 2018 *J. Phys.: Conf. Ser.* **1005** 012015

Aerodynamic Characteristics of Tube-Launched Tandem Wing Unmanned Aerial Vehicle

Nurhayyan H. Rosid[1)*], Irsyad Lukman E.[1)], and Ahmad Fadlillah M.[1)] , M. Agoes Moelyadi[1)]
[1)] Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Indonesia

*nurhayyan.halim.rosid@s.itb.ac.id

Abstract. Tube Launched UAV with expandable tandem-wing configuration becomes one of the most interesting topic to be investigated. Folding wing mechanism is used due to the requirements that the UAV should be folded into tubular launcher. This paper focuses on investigating the aerodynamics characteristics because of the effects of folding wing mechanism, tandem wing configuration, and rapid deploying process from tube launcher. The aerodynamic characteristics investigation is conducted using computational fluid dynamics (CFD) at low Reynolds numbers (Re < 200000). The results of the simulation are used for the development of ITB Tube-launched UAV prototype and for future studies.

Keywords : tandem wing, folding wing, expandable wing, tube-launched UAV, aerodynamic, CFD

1. Introduction

Unmanned Aerial Vehicles (UAVs) have been widely used both in military and civil all across the world in recent year. Many types of UAV technlogies have been developed to answer the global needs, such as for aerial mapping, aerial surveilllence, atmospheric sensing, payload delivering, and for war missions. One of the latest technologies in aerial vehicle is morphing shape which can manipulate it's external shape to achieve better flight performance and to gain other good advantages. Among the various kinds of morphing vehicles, there are certain types of UAV with folded wing that could launch from tubular launcher. The folding wing technology can reduce space usage so the carriage of the UAV can be easier and the packaging can be simplified. On the other hand, the tubular launcher has higer security and faster take off speed than other conventional launching method[1].These adventages are needed in military application helping the troops to carry and to deploy UAV easier. During launching process, the rapid tranformation from folded wing to expanded wing can have significant influence on aerodynamic characteristics,stability and maneuverability. The numerical simulation will be conducted to investigate the aerodynamic characteristic both in transition process and steady level flight.

The small allowable space of tube launcher requires the folding wing mechanism, and the available volume must be utilized to achieve the wing area as large as possible, so the tandem wing configuration is the best choice. Rival D[2] has discovered that tandem-wing system has better better fuel efficiency. The interaction between forward and rear wing generates suction bubble creating thrust addition. Another research done by Rhodes shows that there are some benefits using dual-wing configuration compared to conventional aircraft design. Dual-wing configuration has better cruise performance and lower fuel consumption than single-wing configuration[3].

Aircraft Configuration

The deploying process of tandem-wing UAV with folding mechanism is shown in figure 1. This configuration contains canard (front lifting surface), wing (rear lifting surface), dual vertical tail, and pusher electric propulsion. This configuration is designed to achieve desired lift from 2 lifting surfaces, canard and wing. The wing span is 190 mm longer than canard span. This difference is designed to make aircraft neutral point (NP) moves backward. In order to achieve good longitudinal stability, the center of gravity must be located in front of the neutral point. The center of gravity of this configuration is about 20 mm in front of NP. Aircaft wing is located below the fuselage to anticipate the collision between vertical stabilizer and wing when in rapid deploying proccss. Downwash effect of the canard will be investigated later.

There are some parameters that affect the performance of tandem wing UAV such as the vertical gap between canard and wing denoted as y_L and y_R, distance between canard-wing leading edge denoted as d, small vertical gap between left and right lifting surfaces shown in figure 2, and the size of vertical stabilizer that significantly affects the lateral-directional stability of aircraft.

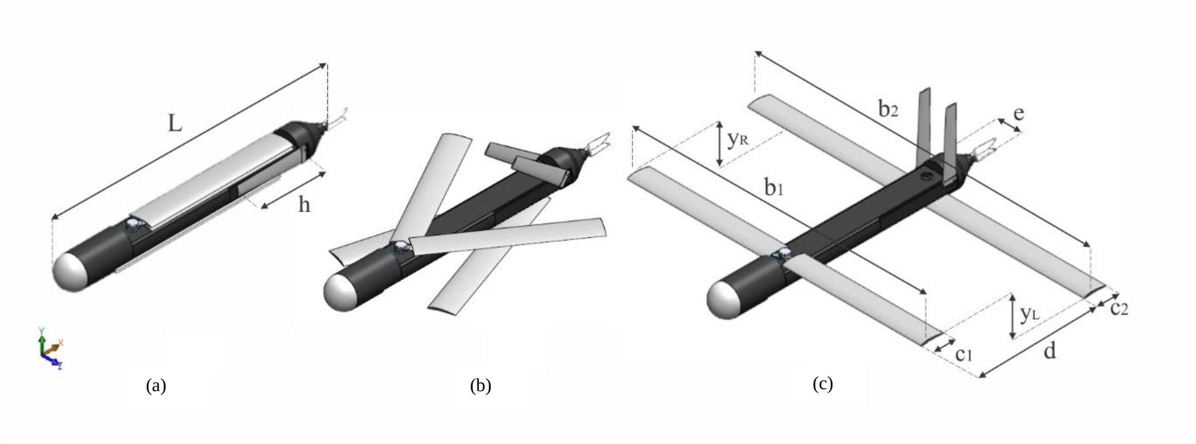


Figure 1. Deploying process : (a) Folded Condition (b) Transition Condition (c) Expanded Condition

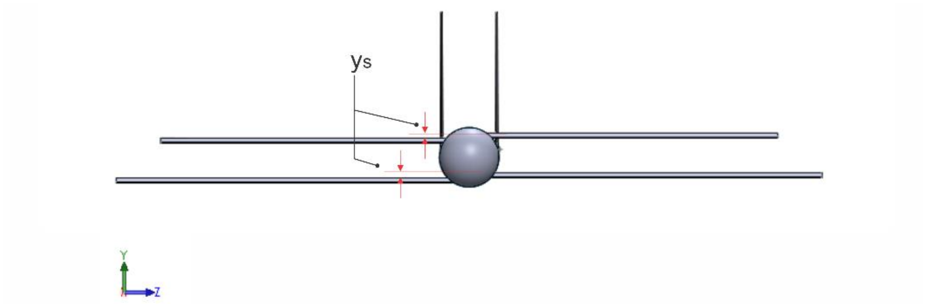


Figure 2. Front view : small vertical gap between left and right lifting surfaces

Table 1. UAV Specification

Definition	Value
Length ***L***	1124 mm
Chord Length ***c1***	100 mm
Chord Length ***c2***	100 mm
Canard Span ***b1***	1318 mm
Wing Span ***b2***	1508 mm
Vertical Stabilizer ***h***	300 mm
Canard-Wing LE distance ***d***	635 mm
Canard-Wing Gap (Left) y_L	75 mm
Canard-Wing Gap (Right) y_R	75 mm
Left-Right Lifting Surfaces Vertical Gap y_S	11 mm
Distance among Vertical stabilizers	118 mm
Canard Airfoil	NACA 6408
Wing Airfoil	NACA 6408
Vertical Stabilizer Airfoil	NACA 0010
MTOW	3 kg
Cruise Speed	25 m/s
Altitude	100 m
S ref	2.69 m^2

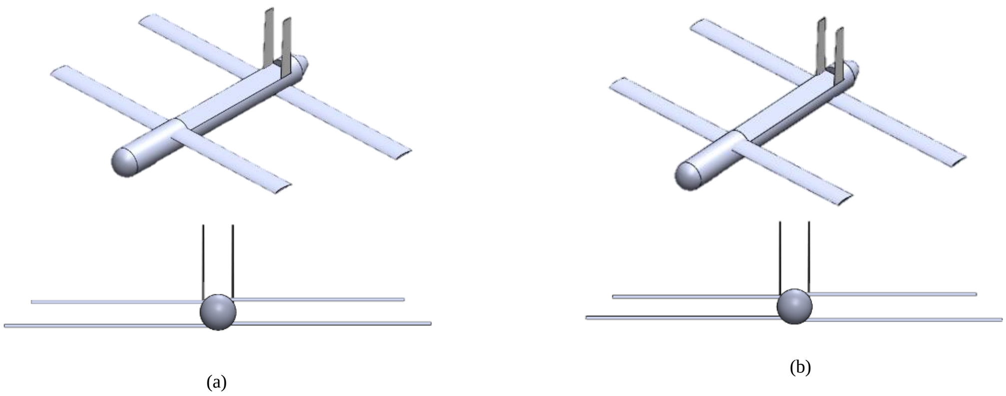


Figure 3. Two types UAV configuration: (a) Model 1 (b) Model 2.

Because of folding wing mechanism, the wing and canard must be separated at symmetric plane of UAV. The left and right wings are joined through wing spar and folding mechanism. Fig. 3 shows two types of configuration in placing lifting surfaces. Model 1 places left canard higher than right canard and also left wing higher than right wing. Meanwhile, model 2 places left wing lower than right wing with the same canrd position as model 1. In this study, the effect of these two different configurations are investigated whether there is difference on lift distribution between left and right section.

2. Numerical Simulation Method

The numerical simulation is conducted using Ansys Software with CFX solver and based on finite volume method. General equation commonly used to represent compressible flow behavior is Navier-Stokes equation which is written as

$$\rho\left[\frac{\partial\mu}{\partial t}+(u\nabla)u\right]=-\nabla p+\mu\nabla^2 u+\frac{1}{3}\mu\nabla(\nabla u)+\rho F \tag{1}$$

Where ρ is the fluid density, μ is the dynamic viscosity, t is the time , u is the fluid velocity vector, and F is the body force vector acting on unit mass of fluid[1]. Because of the estimated cruise speed is about 25 m/s with operating altitude 100 m, the value of Mach number is about 0.07. This small Mach number drives to incompressible flow assumption. For incompressible flow the density is constant

$$\frac{\partial\rho}{\partial t}=0 \tag{2}$$

The continuity equation of fluid can be expressed as

$$\nabla(\rho u)+\frac{\partial\rho}{\partial t}=0 \tag{3}$$

From equation (1),(2), and (3) , the general form of Navier-Stokes equation for incompressible flow can be written as

$$\rho\left[\frac{\partial\mu}{\partial t}+(u\nabla)u\right]=-\nabla p+\mu\nabla^2 u+\rho F \tag{4}$$

In order to achieve good accuracy of drag due to turbulent viscosity , two transport equation are solved for turbulence kinetic energy, k, and turbulence dissipation rate,ε[4]. k- ε turbulence model is the most common model used in CFD to simulate mean flow characteristics for turbulent flow condition.

Rectangular bounding box is chosen for computational domain. The size of the domain is 4.2 m x 3 m x 6 m and the maximum box length is approximately 60 times of the chord. In order to choose appropriate node number, the grid test is performed for several nodes number. The node numbers are from 6.5 x 10^5, 8.2 x 10^5, 1.12 x 10^6,1.13 x 10^6, 1.133 x 10^6, 1.19 x 10^6. Figure 5 shows the effect of node number on lift to drag ratio. Greater node number results in converging value and more accurate.

The computation domain and mesh are shown in fig. 4. In order to capture boundary layer flow, the inflation method is used. Further, in this simulation, flow material is defined as ideal gas. The boundary condition (BC) setup contains inlet BC with 25 m./s of flight velocity at zero angle of attack, boundary condition at ooutlet is defined using static pressure 99700 Pa defined from UAV operating altitude, boundary condition at wall is defined as no slipping wall, and far field regions are defined as opening.

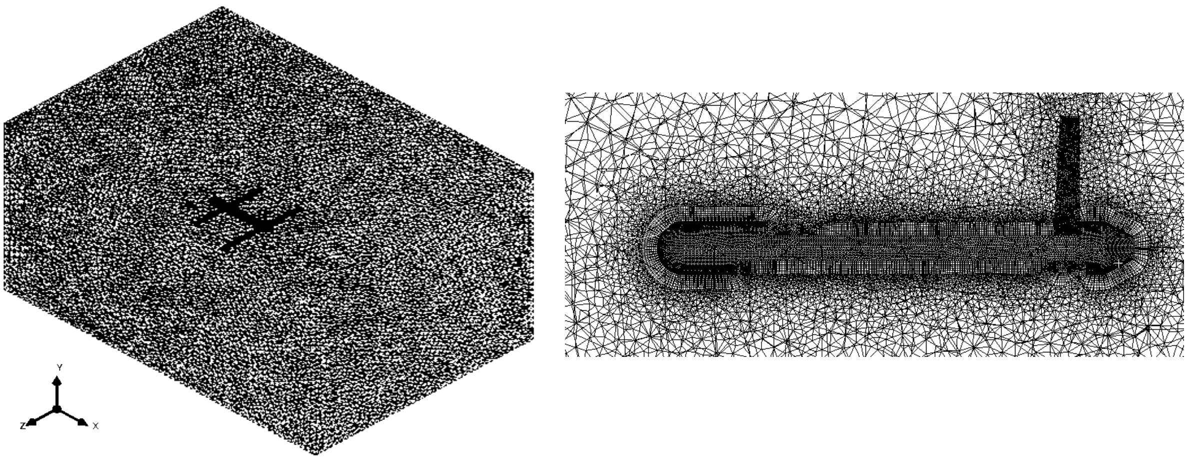


Figure 4. Computation domain and mesh

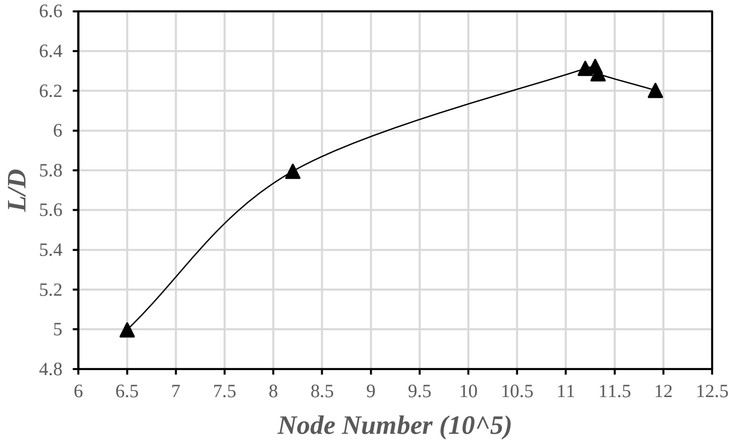
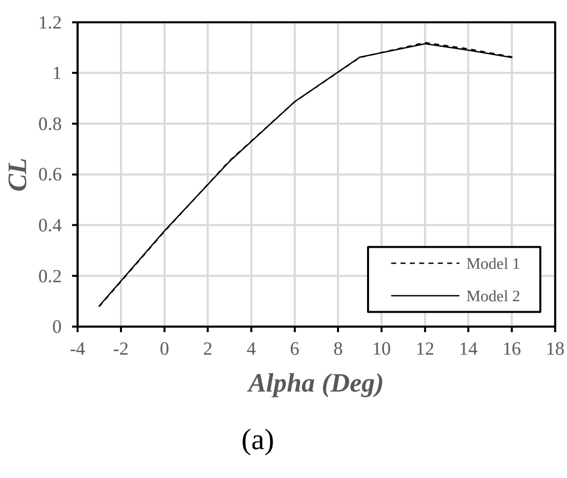


Figure 5. The effect of node number on Lift to drag ratio

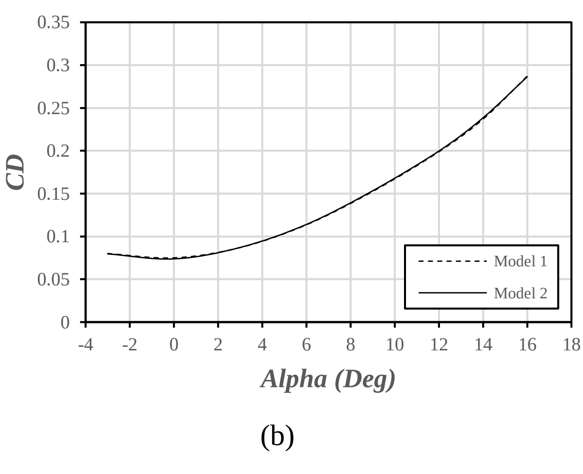
3. Results and Discussions

The numerical simulation on aerodynamic characteristics of two different models with varying angle of attack and with the same boundary condition are presented in figure 6 (a) and (b).The lift and drag coefficient both for two models are almost overlapping. The small difference of lifting surface gap has negligible effect on the lift and drag characteristic of the aircraft. In contrast, there is difference value of roll moment between two models as shown in figure 6 (c). Roll moment of model 1 tends to have greater value than model 2. Both two models have positif roll moment. Roll moment of model 1 keeps increasing until it reaches 12 degree with maximum value 0.36 N.m. Meanwhile, the roll moment of model 2 reaches the maximum value at 6 degree and the magnitude is about 0.25 N.m. As a whole view, model 2 has lower roll moment. At this perspective, lifting surfaces arrangement of model 2 is better than model 1 because it is closer to zero roll moment. Huge roll moment can cause lateral-directional instability of an aircraft.

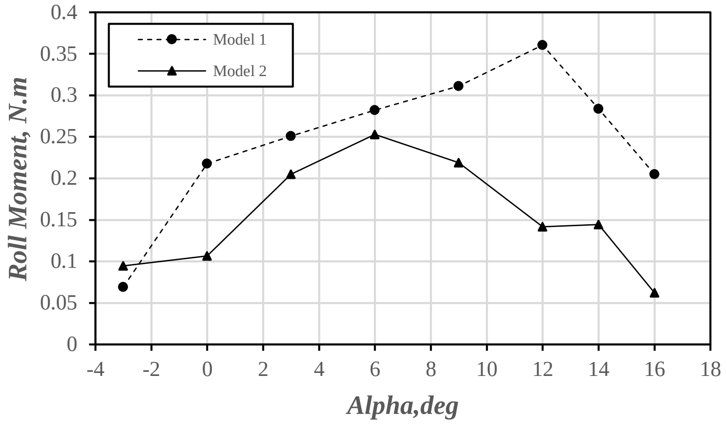
At small angle of attack, both configurations do not visualize any downwash effect generated by canard flow as shown in figure 7. Figure 8 shows streamline velocity for high AoA (9 deg). It is clearly seen that the flow from canard does not give any wash flow effect to the wing. From this result, both configuration is good enough to minimize the canard-wing flow interaction due to downwash effect.



(a)



(b)



(c)

Figure 6. Comparison of the Aerodynamic characteristic for both model 1 and model 2 : (a) Lift Coefficient (b) Drag coefficient (c) Roll moment

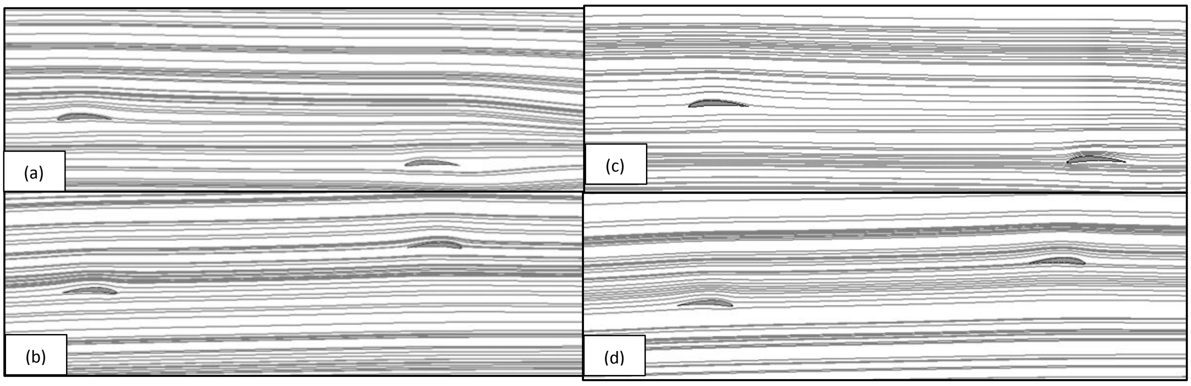


Figure 7. Comparison of the Velocity streamline for both model 1 and model 2 at zero AoA: (a) Model 1 left view (b) Model 1 right view (c) Model 2 left view (d) Model 2 right view

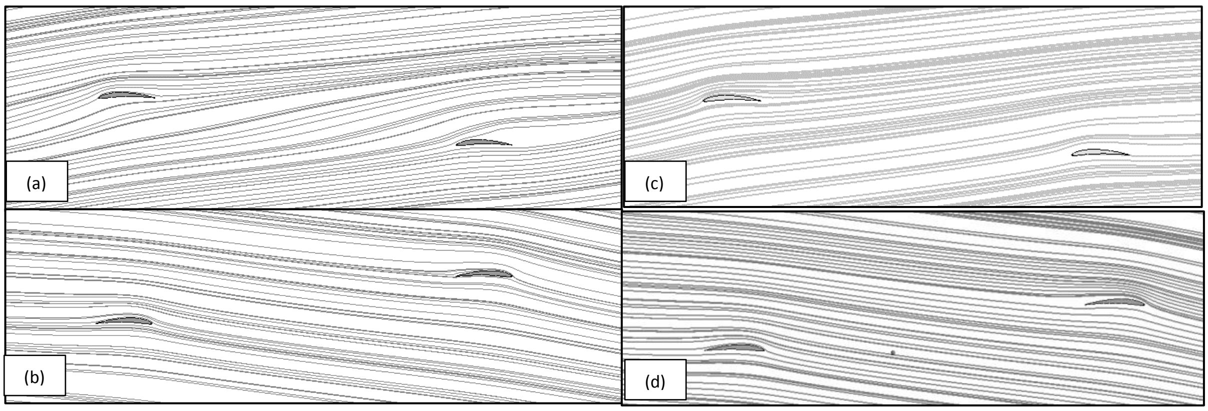


Figure 8. Comparison of the Velocity streamline for both model 1 and model 2 at 9 degree AoA: (a) Model 1 left view (b) Model 1 right view (c) Model 2 left view (d) Model 2 right view

4. Conclusions or Concluding Remarks

For small gap (11 mm) between left and right lifting surfaces, there is no significant differences in lift and drag coefficient for various angle of attack. Model 2 is better than model 1 because it generates less roll moment.

Acknowledgeement

The authors woud like to thank The Indonesian Ministry of Education Directorate General of Higher Education (DIKTI) for financial support and Aksantara UAV Research & Development ITB for providing research laboratory.

References

[1] Liang Gao, Changle Li, Hongzhe Jin, Yanhe Zhu, Jie Zhao and Hegao Cai. Aerodynamic Characteristics of a Novel Catapult Launched Morphing Tandem-Wing Unmanned Aerial Vehicle. *Advances in Mechanical Engineering* 2017, vol. 9.

[2] Y. Zhou, A.M. Anvar. Design and Simulation of New Versions of Tube Launched UAV. *21st International Congress on Modelling and Simulation,* Australia, 2015.

[3] Justin Ott, Daniel Biezad. Design of a Tube-Launched UAV. *AIAA 3rd "Unmanned Unlimited" Technical Conference*,Chicago,2004.

[4] Tony S. Tao. *Design and Development of a High-Altitude, In-Flight-Deployable Micro-UAV*. Cambridge : MIT Lincoln Laboratory, 2010.

[5] Rival D, Hass G and Tropea C. Recovery of energy from leading-and trailing-edge vortices in tandem-airfoil configurations. J Aircr 2011; 48: 203–211.

[6] Rhodes MD and Selberg BP. Benefits of dual wings over single wings for high-performance business airplanes. J Aircr 1984; 21: 116–127.