Jurnal Teknologi

Full paper

Static Stability of a Compound Wing Configuration in Ground Effect

Saeed Jamei[a], Adi Maimun[a*], M. Mobassher Tofa[a], Nor Azwadi[b], Shuhaimi Mansor[c], Agoes Priyanto[a]

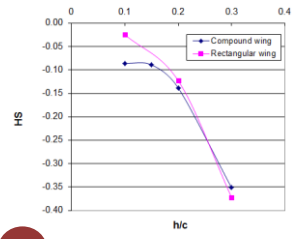
[a]*Department of Marine Technology, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*Department of Termo. Fluids, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[c]*Department of Aeronautical Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: adi@fkm.utm.my

Article history

Received :23 March 2014
Received in revised form :
3 April 2014
Accepted :2 June 2014

Graphical abstract



Abstract

The height static stability of a wing can be a main concern for conceptual design of wing-in-ground effect (WIG) crafts. In this research, the stability of a rectangular and compound wing was computationally predicted in ground effect. A realizable k-ε turbulent model was used for simulation the flow filed over the wing surfaces. First, the drag coefficient and lift to drag ratio of numerical simulation were validated by experimental data of the rectangular wing. Next, the stability of the compound wing respect to different ground clearances will be determined and compared with rectangular wing. This study illustrated a deep understanding of static stability of present compound wing in ground effect, which eventually can be a guideline for researchers and designers of WIG craft.

Keywords: Aerodynamic coefficients; compound wing; static stability: wind tunnel; wing-in-ground effect

1.0 INTRODUCTION

Currently many countries try to use Wing-In-Ground (WIG) crafts as an option for marine transportation. The WIG crafts have many advantages as compared with airplane and fast boat [1] but some problem still exist in conceptual design of WIG craft, for instance, the high resistance during the take-off and stability. Accordingly, the researchers try to find proper design for the hull, wing and stabilizer.

Several numerical and experimental researches have been done to investigate the aerodynamic behavior of wing in proximity to the ground. Yang and Yang [2] investigated on the aerodynamic characteristics of a wing with the tillable endplate. They established that aerodynamic performance of wing can be controlled by the deflection angle of the endplate. The aerodynamic characteristics of a special ram wing concept, which was effectively a compound wing, has been investigated by Jamei *et al.* [3-4]. The compound wing was divided into three parts: the middle part was used as the rectangular wing and the side parts were reverse taper wings with an anhedral angle. The compound wings could create a greater reduction of downwash velocity and modify the pressure distribution on the lower side. The high increment of lift-to-drag ratio for the proposed wing in extreme ground effect recognizes a good efficiency for wing-in-ground (WIG) craft.

Many Researchers were investigated on the static stability of WIG craft [5-8]. Kornev and Matveev [9] found that the profiles of tail wing and main wing are the main factors of static height stability. They suggested that the best range of height stability is between -0.15and -0.05 for WIG craft; lower than -0.15 WIG craft to reach dynamic instability, and if more than -0.05, there would be a weak static stability. Finally, they suggested that for acceptable stability of WIG craft, the centre of gravity should be close to the height of aerodynamic centre (X_h), and it also should be between the height aerodynamic centre and pitch aerodynamic centre (X_α). Irodov [10] recommended a height static stability criterion as follows:

$$HS=X_\alpha-X_h<0 \quad (1)$$

$$X_\alpha=CM_\alpha/CL_\alpha \quad (2)$$

$$X_h=CM_z/CL_z \quad (3)$$

Where CM_α, CL_α, CM_z and CL_z are derivatives of lift and moment coefficient with respect to pitching angle and height. In a stable WIG craft, these derivatives usually are $CL_z>0$, $CM_\alpha<0$, $CL_\alpha>0$ and $CM_z>0$ [5].

The static stability is the main problem in conceptual design of a wing. This study explores the aerodynamic behavior and stability of a rectangular and compound wing configuration [3] during ground effect. The aerodynamic coefficients and height static stability of the compound wing respect to different ground clearances were determined.

2.0 NUMERICAL STUDY OF CFD

The simulation of a compound wing was done with NACA6409 airfoil section. The principal dimensions of the compound wing (Figure 1) are shown in Table 1 [3]. These simulations were prepared with respect to different ground clearance (h/c) and an aspect ratio 1.25. Ground level (h) is defined by the distance between trailing edge of wings center and ground surface. The flow structure around the compound wing was simulated with realizable k-ε turbulent model. The transport equations for the turbulent kinetic energy (k) and turbulent dissipation energy (ε) are expressed as follows.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_{j)}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (4)$$

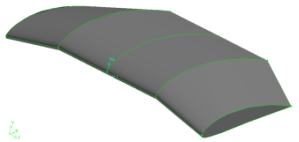
$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \quad (5)$$

$$C_1=\max\left[0.43,\frac{\eta}{\eta+5}\right],\eta=\frac{k}{\varepsilon},S=\sqrt{2S_{ij}S_{ij}} \quad (6)$$

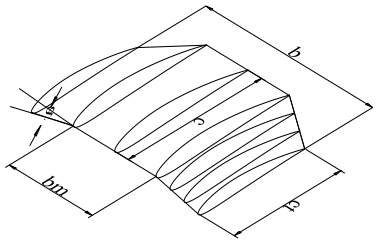
Where S_k and S_ε are user-defined Source terms, $C_{1\varepsilon}$, C2, $C_{3\varepsilon}$, σ_k and σ_ε are the adaptable constants.

The aerodynamic coefficients in this numerical research were determined as follows:

$$C_L=\frac{L}{0.5\rho U^2 A},\quad C_D=\frac{D}{0.5\rho U^2 A},\text{ and }\quad C_M=\frac{M}{0.5\rho U^2 Ac}$$



(a)



(b)

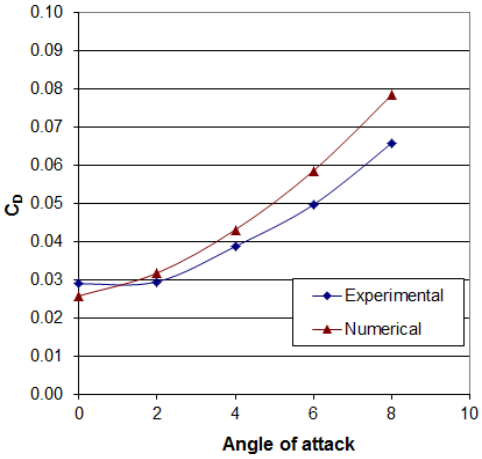
Figure 1 (a)Compound wing, (b) Geometry of the compound wing

Table 1 Principal dimension of wings

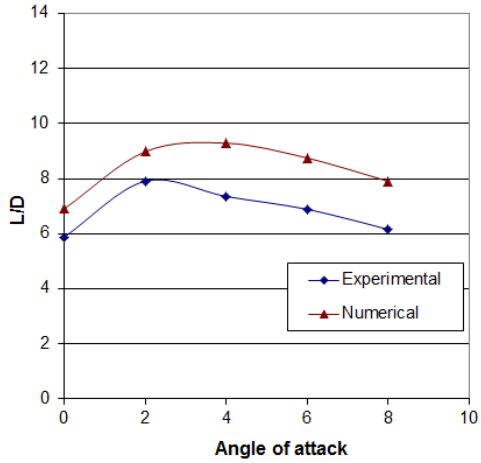
	Rectangular wing	Compound wing
Total wing span (b)	250 mm	250 mm
Root chord length (c)	200 mm	200 mm
Middle wing span (bm)	-	125mm
Taper ratio (c/ ct)	-	1.25
Anhedral angle (a)	-	13°

3.0 VALIDATION OF NUMERICAL STUDY

The numerical simulations were compared with experimental data of test model using the low speed wind tunnel at the Universiti Teknologi Malaysia. Figure 2a-b illustrates the drag coefficient and lift to drag ratio of the rectangular wing at ground clearance of 0.15 versus angle of attack. These Figures depict numerical and experimental simulations have similar tendency, however the numerical results had some deviations from experimental [11].



(a) Drag coefficient



(b) Lift to drag ratio

Figure 2 Comparison of experimental and numerical simulation of the rectangular at ground clearance of 0.15: (a) Drag coefficient; (b) Lift to drag ratio

4.0 RESULTS AND DISCUSSION

The aerodynamic coefficients of wings (Table 1) versus ground clearance for different angles of attack are shown in Figures 3-6. Figure 3 shows the lift coefficients increased as the wings reached to ground, especially at the low ground clearance there are dramatic increase. Compound wing had a considerable enhancement, where the lift coefficient of the compound wing was higher than the rectangular wing for both angles of attack. Based on the present results, the development of the ram pressure effect under the compound wing is greater than the rectangular wing. At the ground clearance of 0.1, the increments of lift coefficient of the compound wing related to the rectangular wing were 17.3 and 16.1% for angles of attack of 4° and 6° respectively.

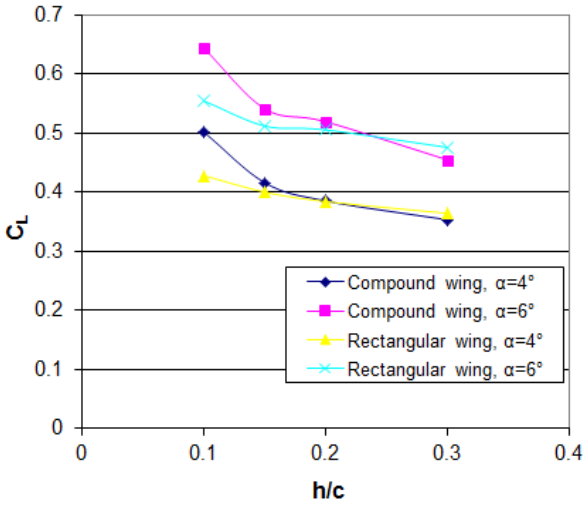


Figure 3 Lift coefficient (CL) of the compound wing and the rectangular wing versus ground clearance (h/c) at angles of attack of 4° and 6°

Figure 4 shows a slight difference in the drag coefficient of both wings when the ground clearance increased for angle of attack of 4° but there are some fluctuations at angle of attack of 6°. The drag coefficient plots of the compound wing were lower than the rectangular wing, because the tip vortex of the compound wing is weaker that of the rectangular wing. At the ground clearance of 0.2, the reductions of drag coefficient of the compound wing related to the rectangular wing were 7 and 6.3% for angles of attack 4° and 6° respectively.

Figure 5 depicts the moment coefficients of the compound wing and the rectangular wing (Table 1) versus the ground clearance are. A moment coefficient that caused a decrease in the angle of attack was defined as a positive moment. The moment coefficients of both wings were greater at higher angle of attack. The plot of the compound wing is lower than the rectangular wing for both angles of attack but these reductions were smaller at low angle of attack. At the ground clearance of 0.1, the reductions of moment coefficients of the compound wing related to the rectangular wing were 2.7 and 5.7% for angles of attack of 4° and 6° respectively.

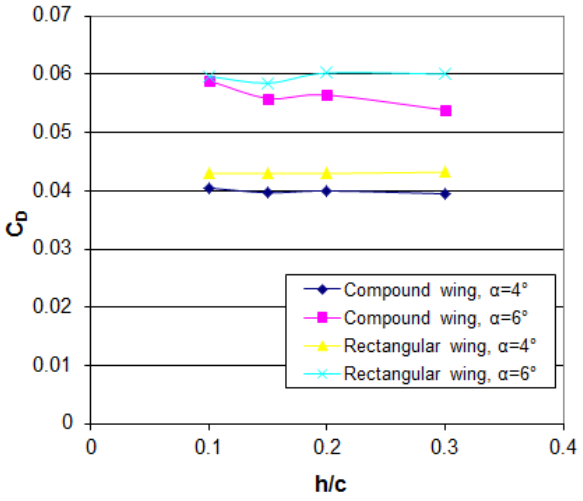


Figure 4 Drag coefficient (CD) of the compound wing and the rectangular wing versus ground clearance (h/c) at angles of attack of 4° and 6°

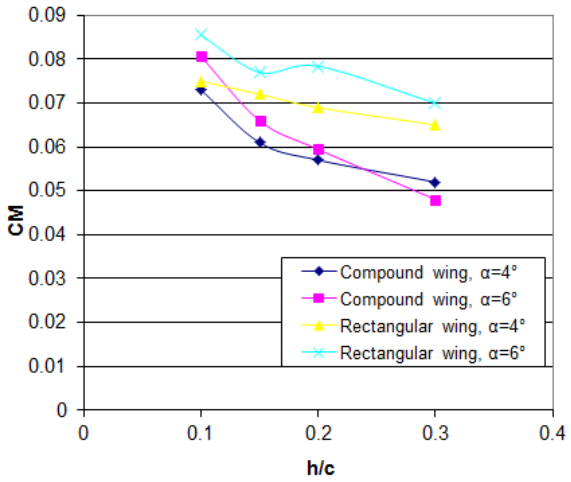


Figure 5 Moment coefficient (CM) of the compound wing and the rectangular wing versus ground clearance (h/c) at angles of attack of 4° and 6°

Based on the aerodynamics centers, the height static stability (HS) [10] of the compound wing and the rectangular wing was predicted as shown in Figure 6. The height static stability of the compound wing is lower than the rectangular one at low ground clearance; this shows better range of static stability for the compound wing. However, the magnitude of the height static stability (HS) of wings had no more differences when the ground clearance enhanced. This perfection of the static stability could be related to the design of the compound wing.

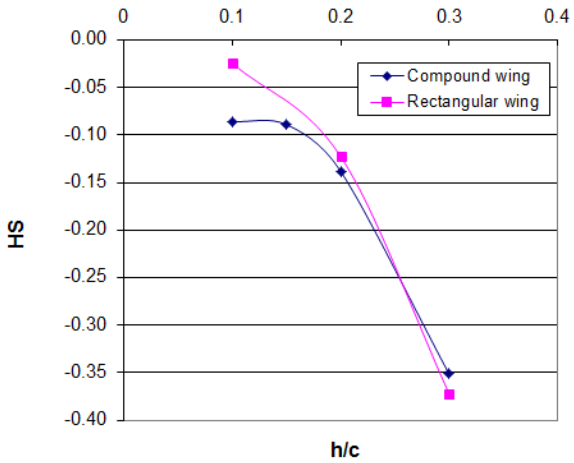


Figure 6 Height static stability (HS) of the compound wing and the rectangular wing versus ground clearance (h/c) at angle of attack of 4°

■6.0 CONCLUSION

This study numerically carried out the height static stability of a compound wing during ground effect. The aerodynamic coefficients and the height static stability of the compound wing and the rectangular wing were compared. Accordingly, the lift and drag coefficients of the compound wing had noticeable improvement compared to the rectangular wing especially at low ground clearance. The static stability of the compound wing was higher that of the rectangular wing at low ground clearance. However, when wings reached to the ground the static stability dropped.

Acknowledgement

The authors would like to thank the Ministry of Science, Technology, and Innovation (MOSTI) Malaysia for funding this research.

References

[1] Rozhdestvensky, K.V. 2006. Wing-in-ground Effect Vehicles. *Journal of Aerospace Science.* 42: 211–283.
[2] Yang, W., and Z. Yang. 2012. Aerodynamic Investigation on Tillable Endplate for WIG craft. *Aircraft Engineering and Aerospace Technology.* 84(1): 4–12.
[3] Jamei, S., A. Maimun, S. Mansor, N. Azwadi, and A. Priyanto. 2012. Numerical Investigation on Aerodynamic Characteristics of a Compound Wing In Ground Effect. *Journal of Aircraft.* 49(5): 1297–1305.
[4] Jamei, S., A. Maimun, S. Mansor, N. Azwadi, and A. Priyanto. 2011. Numerical Investigation on Performance and Environmental Impact o0f A Compound Wing In Ground Effect. Proceedings of WSEAS/NAUN the 2nd International Conference on Fluid Mechanics and Heat and Mass Transfer. 14-17 July. Greece: Corfu Island. 207–214.
[5] Kim, H. J., H. H. Chun, and K. H. Jung. 2009. Aeronumeric Optimal Design of a Wing-in-Ground Effect Craft. *Journal of Marine Science and Technology.* 14: 39–50.
[6] Yang, W., Z. Yang, and C. Ying. 2010. Effects of Design Parameters on Longitudinal Static Stability for WIG Craft. *International Journal of Aerodynamics.* 1(1): 97–113.
[7] Park, K., and J. Lee. 2008. Influence of Endplate on Aerodynamic Characteristics of Low-aspect-ratio Wing in Ground Effect. *Journal of Mechanical Science and Technology.* 22: 2578–2589.
[8] Lee, J., C. S. Han, and C. H. Bae. 2010. Influence of Wing Configurations on Aerodynamic Characteristics of Wings in Ground Effect. *Journal of Aircraft.* 47(3): 1030–1040.
[9] Kornev, N., and K.Matveev. 2003. Complex Numerical Modeling of Dynamics and Crashes of Wing-in-Ground Vehicles. AIAA Paper. 600: 1–9.
[10] Irodov,R.D. 1970. Criteria of Longitudinal Stability of Ekranoplan. UcheniyeZapiski TSAGI. 1(4): 63–74.
[11] Jamei, S. 2012. Aerodynamic Characteristics of Compound Wing Configuration of Wing-in-Ground Effect Vehicle. PhD Thesis. Faculty of Mechanical Engineering, Universiti Teknologi Malaysia.