PERINTIS eJournal, **2021**, Vol. 11, No. 1, pp. 61-69

EFFECT OF MICRO-RAMP VORTEX GENERATOR IN IMPROVING AERODYNAMICS PERFORMANCE OF WING-IN-GROUND CRAFT FUSELAGE

AAT Syahin[1], M Zinnyrah[1], NA Azfar[1], I Said[1],A Che Idris[2], MRA Rahman[1,3], MR Saad[1,]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Perdana Sungai Besi, 57000 Kuala Lumpur, Malaysia
[2]Faculty of Integrated Technologies, Universiti Brunei Darussalam, BE1410 Brunei Darussalam
[3]Centre for Defence Research and Technology (CODRAT), Universiti Pertahanan Nasional Malaysia, Kem Perdana Sungai Besi, 57000 Kuala Lumpur, Malaysia

*Corresponding author: mohdrashdan@gmail.com

ABSTRACT

A wing-in-ground (WIG) vehicle is designed to fly above the water surface at an altitude lower than its wing chord. This is due to the positive ground effect as it creates lift and reduce the effect of aerodynamic drag thus enhancing the overall efficiency of the wing. However, the current WIG craft has shown significant hydrodynamic and aerodynamic drag against the hull-fuselage during take-off and cruising. These phenomena will lead to the flow separation and inclination effects on drag, which explains the abundant of research on flow control devices installed on the WIG hull-fuselage. Therefore, the aim of this study is to investigate the effect of flow control devices, known as micro-ramp vortex generator (MVG) towards the aerodynamic performance of WIG hull-fuselage through wind tunnel experiments. The models were tested in the flow velocity within the range of 1m/s to 10m/s with Reynolds number of 8.6 x 10^4. From this investigation, the finding shows that there is a reduction of drag of 21% with the present of MVG in comparison to the baseline case. This indicates that the Micro-Ramp MVG has a high potential to be used as flow control device in improving the aerodynamics efficiency on a WIG craft.

***Keywords**: Wing-In-Ground Craft, Flow Control, MVG, Subsonic Wind Tunnel*

1.0 INTRODUCTION

Wing-in-ground (WIG) effect craft has a unique design concept and simple operating mechanisms that viable in many areas such as military functions, tourisms, and cargo transportation. WIG craft provides an alternative solution for air transportation even though it is not commercially applicable for public transport. Briefly, the ground effect (GE) is a natural phenomenon that occurs when the lift-to-drag ratio increases while cruising close to the water or ground surface [1]. The research on ground effect was firstly examined by Wieselsberger [2], who investigated the effect of induced lift and drag on the wing at different altitude using the Lanchester-Prandthl theory and found that the lift performance increases while drag formation decreases as the wing closes near to the ground. Back in 2002, Moore et al. [3]demonstrated an experimental investigation of the DHMTU airfoil geometry with different angle of attack (AoA) at various altitude. They discovered that the percentage of lift coefficients can increase up to 15.7% and the drag coefficient percentage can be reduced up to 5.6% when the AoA increases within the range of -9^{o} to 21^{o} and the wing to ground distance decreases from a distance of 5C to 0.3C. With the same intention, Tofa et al. [4] experimentally investigated the effect of WIG craft model and compound wing with and without endplate on the lift to drag ratio. They found that the craft with endplates increases the lift and drag ratio of WIG as well as improving the efficiency of aerodynamic without disturbing the longitudinal stability.

Modification in mechanical design for obtaining the benefit of GE has been widely introduced in WIG scope. There are two most common method that are practically used to control the fluid flow, known as active flow control and passive flow control. Similar to previous studies like [3] and [4], the aim is to achieve a higher number of lift to drag ratio, but the modern technique is to apply any of these two flow control techniques in the investigation. The basic knowledge of active and passive flow control devices is crucial in terms of the fundamental physics flow so that this concept can be fully understood when it applies to WIG. For active flow control, the mechanism can be seen through the investigation conducted by Boermans [5] regarding the elimination of boundary layer using the method of flow suction on the airfoil. Maldonado et al. [6] and Zhang et al. [7] proposed the drag reduction method by performing a synthetic jet to create vortices and a higher momentum boundary layer in the flow. Other researcher like Schaeffler et al. [8] focused on Zero-Net-Mass-Flux blowing jets overflow by changing the phase angle of the blowing jets resulted in a good reduction in lower mean drag value.

In contrast with active flow control, passive flow control does not require external energy to operate. Ashby [9] proved that the installation of both airfoil and trailing edge was able to increase the lift coefficient in respect to the baseline configuration. Lin [10] studied the sub-boundary layer vane vortex generator that results in a significant improvements of flow separation reduction compared to the baseline test where there was a larger conventional counterpart without the effects of increased drag. In 2006, Anderson et al. [11] showed an interest to study the effect of Micro-Ramp and Micro-Vane Vortex Generator (VG) on the shock boundary layer interactions (SBLI) with different height, chord length and spanwise. From the investigation, they discovered that the Micro-Ramp is able to reduce more SBLI compared to the Micro-Vane in a supersonic flow. Soon, Babinsky et al. [12] measured the wake velocity decay resulted from micro ramps with different heights. Their studies discovered that the maximum deficit velocity, minimum velocity within the wake region, follows a similar trajectory when the wake is scaled with ramp height. As a result, the ramp height is later commonly chosen as the length scaling parameter. Later, Saad et al. [13] conducted the experiment on a hypersonic flow condition based on the design from Anderson et al. [11] and Babinsky et al. [12] to study the effect of shock wave on different type of Micro-Ramp. The outcome shows that the Micro-Ramp delays the pressure rise and reduces the upstream interaction length towards the flow separation regime. Due to the lack of interest for a subsonic flow research, therefore this study is conducted experimentally to investigates the effect of flow control devices, known as Micro-Ramp Vortex Generator (MVG) towards the aerodynamic performance on a WIG hull-fuselage.

2.0 METHODOLOGY

2.1 WIG CAD Model

The design fuselage of the WIG model was taken from the Airfish 8 WIG type with a backward facing step [14]. Due to the test section volume restriction of the wind tunnel which is fixed at 1.0 m x 0.3 m x 0.3 m (length x width x height), the size of the WIG fuselage was modified and scaled down approximately to 1:55 at 0.33 m, 0.08 m, 0.09 m corresponding to the length, width and height respectively, as shown in figure 1. This is also a similar model conducted by Said et al. [15]. A small circular hole was created at the side of the body, center of the fuselage in order to mount the WIG model firmly in the wind tunnel test section [14]. All the models were constructed using SOLIDWORKS Computer Aided Design (CAD). Since the experiment is to study the effect on drag coefficient, C_D by varying the streamwise and spacing location of the MVG at the backward face step location, a slot was intentionally constructed at the bottom of the fuselage so that interchangeable parts of streamwise and spacing Micro-Ramp MVG configuration could be easily replaced.

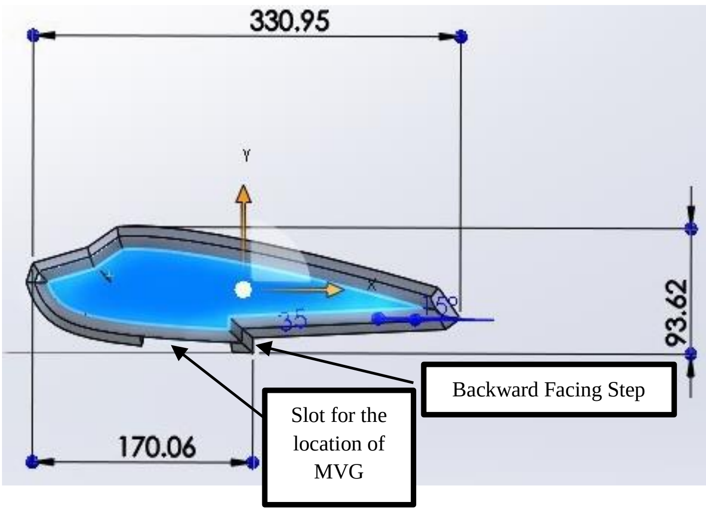

Figure 1 Side View of the WIG fuselage model (All measurements in mm)

2.2 Micro Ramp Vortex Generator Design

According to Boniface [16], Micro-Ramp MVG has a better efficiency for drag reduction and flow separation compared to vane type. The size of the MVG was chosen based on the

boundary layer thickness which is about 3 mm in height acquired from Said et al. [15]. Although the Micro-Ramp design was based on the optimum parameters by Gordard & Stanislas [17], several dimensions need to be adjusted due to manufacturing constraint. Thus, distance to the detachment point (initial fuselage nose point), ΔX_{VG} was set as 0.14 mm (figure 2). On the other hand, the spanwise spacing, λ of the MVG in this project were measured at 14.85 mm with a ratio of 7.5h, where h is the height of MVG [11]. The baseline case study was similar to the model of Aider et al. [18], but changes were made to this design so that the MVG array does not cover the full fuselage width to avoid strong interaction between MVG and the trailing edge. Then, design was tested experimentally.
The requirement test to obtain a quantitative aerodynamic performance, was by using the drag coefficient in the drag equation to measure the index value based on air velocity and properties, position and shape or geometry. Thus, the drag coefficient is obtained in the drag as in equation 1:

$$C_D = \frac{2F_D}{\rho V^2 A_s} \tag{1}$$

where, F_D is the drag force obtained from the force balance of the wind tunnel converted in Newton, ρ is the air density, V is the wind tunnel air speed and A_s is the WIG fuselage area.

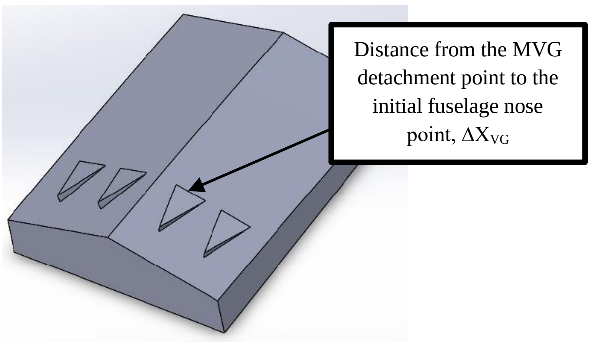

Figure 2 Micro-Ramp configuration for MVG slot model, $\Delta X_{VG} = 0.14$mm

2.3 Fabrication of WIG Model and Micro-Ramp

After the WIG fuselage model and MVG Micro-Ramp slot was designed using CAD, the model was fabricated using a 3D printing device model CR10-S5. Primarily, the base of the 3D printer plate was heated up at approximately 55°C before the nozzle containing a very high temperature PLA filament is melted and travel along the plate as per the real design while extruding the filament out of the nozzle. As the printing is completed, sanding process was done on the surface model so that burrs and other rough surfaces are removed and smoothened as shown in figure 3. These surface especially at the edge of the model must be even because any outer skin roughness will affect the flow reading measurement during wind tunnel testing.

PERINTIS eJournal

PERINTIS eJournal, **2021**, Vol. 11, No. 1, pp. 61-69

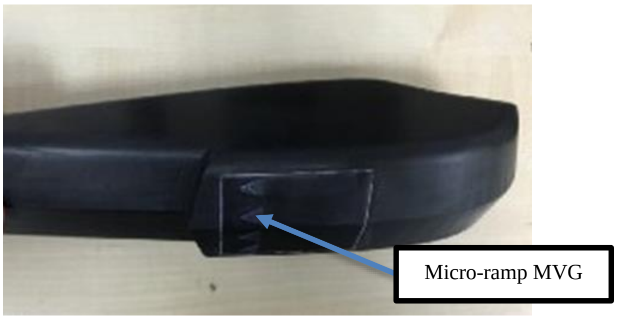

Figure 3 WIG fuselage model with MVG micro-ramp attached together after sanding process was completed

2.4 Wind Tunnel Testing

The experiments were conducted in the Longwin LW-9300R low speed wind tunnel open loop type located at National Defence University of Malaysia (UPNM) as shown in figure 4. The free stream velocity for this experiment was set from 1m/s to 10m/s while the Reynolds number, Re is 8.6 x 10^4. WIG fuselage model was attached with a circular rod from a 3-component force balance equipment located 0.15 m from the starting point of test section as shown in figure 5. This force balance equipment is capable in measuring the drag force, F_D and lift force, $F_{L.}$ Note that the airflow is from left to right.

Figure 4 Overview of LW-9300R Wind Tunnel (left) [19] and monitoring display (right).

PERINTIS eJournal

PERINTIS eJournal, **2021**, Vol. 11, No. 1, pp. 61-69

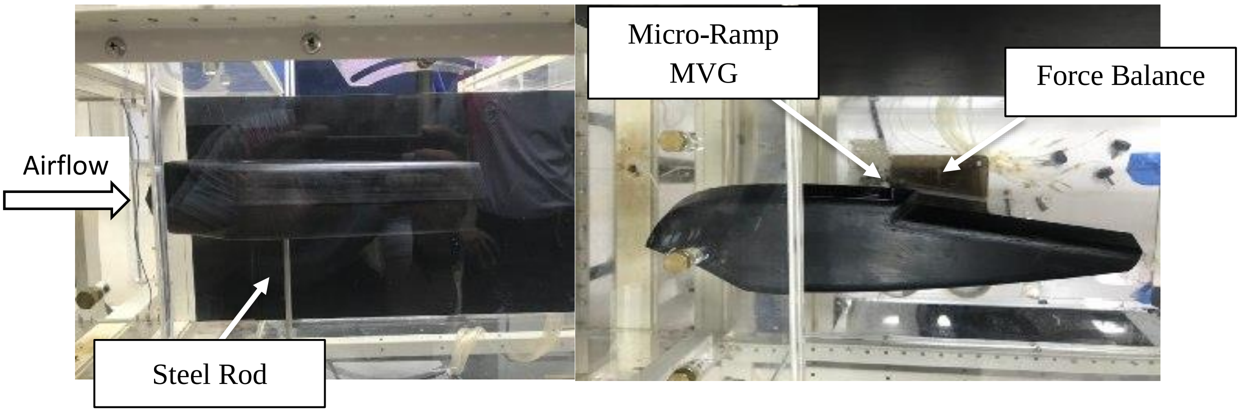

Figure 5 Top view (left) and side view (right) of the Micro-Ramp MVG slot on the WIG fuselage a 3-component force balance connected by a steel rod during experimental testing.

3.0 RESULTS AND DISCUSSION

The experiment was carried out in the wind tunnel to obtain the relationship of the streamwise location spacings between MVG towards drag coefficient, C_D and Drag Force, F_D from 1m/s to 10m/s. Primarily, the WIG fuselage was tested with a baseline slot model to obtain a reference point for the comparison of the Micro-Ramp slot testing later conducted in this experiment. Figure 6 and 7 shows the trend of data of drag coefficient, C_D and drag force, F_D respectively, of WIG Craft fuselage of the baseline slot model. It can be seen that C_D almost has a linear trend from 1m/s air flow speed to 10m/s. The experiment was repeated 3 times to get the average value of data to reduce measurement error of wind tunnel measurement sensor.

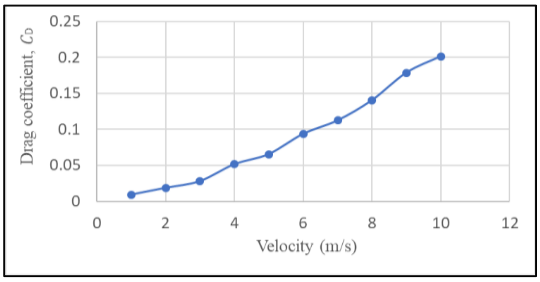

Figure 6 C_D of WIG Craft fuselage with the baseline slot model

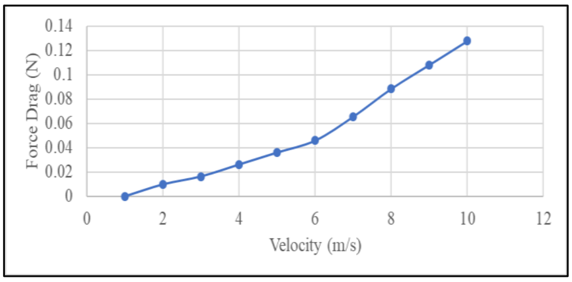

Figure 7 F_D of WIG Craft fuselage with the baseline slot model

Next, the results of the fuselage with the installation of Micro-Ramp are shown in Figure 8, with direct comparison to the baseline case (no Micro-Ramp). Based on the result obtained, it shows that the WIG Craft with Micro-Ramp MVG slot model, experienced lower drag coefficient, C_D than with baseline slot. Although there were minor changes from 2m/s to 3m/s, a better performance of the drag force can be seen where the velocity starts to rise from the 3m/s marks. This proves that the MVG has produced an improvement towards the reduction of drag coefficient of the fuselage. The lowest drag coefficient differential can be seen at 6m/s with a difference of 0.0281 (21%) in comparison with baseline F_D. The presence of Micro-Ramp has proven to reduce drag and at the same time gives a better performance efficiency.

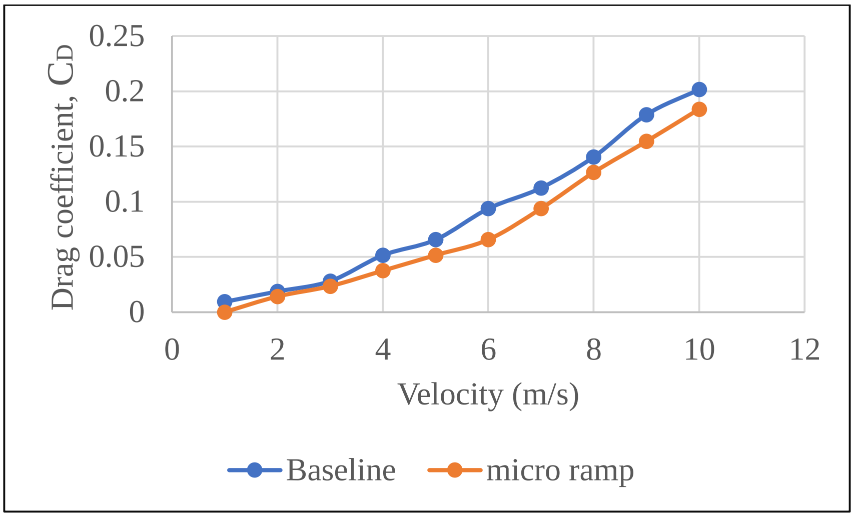

Figure 8 C_D of WIG Craft with baseline slot and Micro-Ramp

This agrees with Lee and Ko [20] through their experiment through PIV analysis that flows control was observed at low C_D while concluded that flow control has the tendency to use in a wide application of WIG craft applications. Consequently, in anther experiment, Micro-Ramp also can be seen to be the most effective surface flow using the similar analysis from previous study obtained by Ye et al. [21].Unfortunately, this investigation never considered the effective surface flow of vane type. Therefore, in comparison to Said et al. [15], the highest drag reduction can be seen to reach up to 25% lower with the installment vane type flow control than baseline case. The result affected is seen through the difference in surface roughness of flow control and gap spacing between the MVG slot and WIG fuselage. Nevertheless, each experiment gives the benefits of drag reduction with proven studies using PIV visualization technique towards WIG and the shape surface of flow control. In summary, the presence of the MVG were able to reduce the flow separation of the hull-fuselage towards the positive ground effect.

4.0 CONCLUSION

Based on the installment of the MVG flow control on the WIG fuselage, the C_D and F_D has shown an improved aerodynamic performance compared to the baseline case. Different streamwise and spacing were identified and the best configuration was tested. From the speed of 1m/s to 10m/s, the C_D in comparison with the baseline model was seen to decrease for about 21%. For future work, further investigation can be done to improve the flow study such as smoke and PIV technique since it will give a better understanding of flow control towards the effect of drag on a WIG craft.

PERINTIS eJournal, **2021**, Vol. 11, No. 1, pp. 61-69

Acknowledgement
This research was supported by the Ministry of Higher Education (MOHE) through the funding from UPNM/STFC-NEWTON/2018/TK/01. The authors also want to thank Universiti Pertahanan Nasional Malaysia (UPNM) for sponsoring the project through Graduate Research Assistant Fellowship under PPPI Trust Fund UPNM.

REFERENCES

[1] Sakornsin R., Thipyopas C., and Atipan S. (2020). Experimental Investigation of the Ground Effect of WIG Craft-NEW1 Model. *Proceedings*, 2019, 39(1), 17.

[2] Wieselsberger, C. (1922). Wing resistance near the ground. Technical Memorandum No. 77 (*NACA-TM-77). National Advisory Committee for Aeronautics.*

[3] Moore, N., Wilson, P., and Peters, A. (2002). An investigation into wing in ground effect aerofoil geometry. *Challenges in Dynamics, System Identification, Control and Handling Qualities for Land, Air, Sea and Space Vehicles*, 11(1), 11-20.

[4] Tofa, M. M., Maimun, A., Ahmed, Y. M., Jamei, S., Priyanto, A., and Rahimuddin. (2014). Experimental investigation of a wing-in-ground effect craft. *Scientific World Journal*, 2014, 489-308.

[5] Boermans, L. (2008). Practical implementations of boundary layer suction for drag reduction and lift enhancement at low speed. KATnet II Workshop 4, Ascot UK.

[6] Maldonado, V., Farnsworth, J., Gressick, W., and Amitay, M. (2010). Active control of flow separation and structural vibrations of wind turbine blades. *Wind Energy, 13*(2-3), 221-237.

[7] Zhang, Z., Yu, X., and Liu, B. (2012). Characteristics of the Tip Leakage Vortex in a Low-Speed Axial Compressor With Different Rotor Tip Gaps. *Proceedings of the 201 ASME Turbo Expo: Turbine Technical Conference and Exposition* 2012. 1-12.

[8] Schaeffler, N., Allan, B., Lienard, C., and Lepape, A. (2010). Progress towards fuselage drag reduction via active flow control: A combined CFD and experimental effort. *36th European Rotorcraft Forum Proceedings*, 1-17.

[9] Ashby, D. (1996). Experimental and computational investigation of lift-enhancing tabs on a multi-element airfoil. Technical Memorandum No. 110432 (*NASA-TM-110432). National Aeronautics and Space Administration.*

[10] Lin, J. (1999). Control of turbulent boundary-layer separation using micro-vortex generators. *Proceedings of the 30th Fluid Dynamics Conference*. AIAA.

[11] Anderson, B., Tinapple, J., and Surber, L. (2006). Optimal control of shock wave turbulent boundary layer interactions using micro-array actuation. *Proceedings of 3rd AIAA Flow Control Conference.* 1-14. AIAA.

[12] Babinsky, H., Li, Y., and Ford, C. P. (2009). Microramp control of supersonic oblique shock-wave/boundary-layer interactions. Proceedings of *49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition,* 47(3), 668-675. AIAA.

[13] Saad, M. R., Zare-Behtash, H., Che-Idris, A., and Kontis, K. (2012). Micro-ramps for hypersonic flow control. *Micromachines, 3*(2), 364-378.

[14] Fach, K. (1999). Classification experience with an 8 seater WIG craft. *Proceedings of the 5th International Conference on Fast Sea Transportation, 339-349.* TU Delft.

[15] Said, I., Rahman, M. R. A., Idris, A. C., Sakri, F. M., and Saad, M. R. (2020). The Effect of Flow Control on Wing-In-Ground Craft Hull-Fuselage for Improved Aerodynamics Performance. *Proceedings of International Conference of Aerospace and Mechanical Engineering 2019,* 501-519. Springer.

[16] Boniface, J.C. (2016). A computational framework for helicopter fuselage drag reduction using vortex generators. *Journal of the American Helicopter Society*, 61(3), 1-13.

[17] Godard, G., and Stanislas, M. (2006). Control of a decelerating boundary layer. Part 1: Optimization of passive vortex generators. *Aerospace Science and Technology, 10*(3), 181-191.

[18] Aider, J. L., Beaudoin, J.-F., and Wesfreid, J. (2009). Drag and lift reduction of a 3D bluff-body using active vortex generators. *Experiments in Fluids,* 48(5), 771-789.

[19] Baljit, S., Saad, M., Nasib, A., Sani, A., Rahman, M., and Idris, A.C. (2017). Suction and blowing flow control on airfoil for drag reduction in subsonic flow. *Journal of Physics: Conference Series,* 914(1), 012-009.

[20] Lee, T., and Ko, L. (2018). Ground effect on the vortex flow and aerodynamics of a slender delta wing. *J. Fluids Eng. 140*(7) 071104.

[21] Ye, Q., Schrijer, F. F., and Scarano, F. (2016). Geometry effect of isolated roughness on boundary layer transition investigated by tomographic PIV. *International Journal of Heat and Fluid Flow,* 61, 31-44.