Experimental Investigation of the Ground Effect of WIG Craft—NEW1 Model †

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Abstract: Navy Experimental Wing-in-Ground-Effect (WIG) craft namely as NEW1, is the first version of 2-seated WIG craft which has been designed and developed by Royal Thai Navy since 2017. This experimental research is a part of the NEW1 project which aims to investigate the aerodynamic characteristics and aspects of the flow passing through the WIG craft model when in ground effect. In the experiment, the WIG craft—NEW1 of 1:15 scale model is tested in a close circuit wind tunnel of 1 m × 1 m test section at Kasetsart University. The tests are conducted at the free stream velocity of 40 m/s or Reynolds number of 280,000, at angles of attack ranging from −9° to 21°, and at the wing to ground distances ranging from 5.0 C to 0.3 C. The measurement of 6-DoF of forces and moments and pressure distributions on the ground surface underneath the WIG craft model are made during the tests. The results show that the ground has significant effects on the aerodynamic characteristics of the WIG craft model when the wing to ground distance is less than its mean chord. It was found that when the model move from 5.0 C (out of ground effect) to 0.3 C, the lift coefficient increases up to 15.7%, the drag coefficient decreases up to 5.6%, and the lift to drag ratio increases 33.4%. The proximity of the model to the ground also affects the longitudinal stability of the model. The moment coefficient curves against angle of attack has negative slope for both in and out of ground effect indicating favorable longitudinal stability. However, it was found that the aerodynamic center move further aft toward the trailing edge when the model move closer to the ground.

Keywords: Wing in Ground Effect; WIG Craft; Wind Tunnel Test; Aerodynamics

1. Introduction

Wing in Ground Effect craft or WIG craft is a vehicle flying above the ground or water surface with an altitude lower than its wing chord. At this height, the ground effect helps in creating more lift and reducing drag hence improving the overall efficiency of the wing. Moore et al. [1] performed experimental tests on the ground effect of the DHMTU airfoil wing model. They found that the lift coefficient could increase by 36% and the drag coefficient could decrease by 21% when the wing was positioned at 20% chord above the ground. Tofa et al. [2] found on the aerodynamic tests on their wing in ground effect craft that the lift to drag ratio increased by 45% when the wing was 20% chord above the ground. Rattapol et al. [3] also investigated seabird-like wings in ground effect and found that the lift to drag ratio of the seabird-like wing could increase by 80% when it was 20% chord above the ground.
With the advantages of the ground effect, WIG crafts are suitable to be used for overseas transportation, especially in archipelago region. Since 1960s, many countries has successful developed a number of WIG craft, for example the Chinese TY-1 [4], the Soviet 400-ton Lun, and 140-ton Orlyonok [5]. However, the recent practical operation of the WIG craft still faces some unresolved difficulties such as stability and maneuverability both in and out of ground effect. In 2016, Royal Thai Navy established a research and development program creating the first prototype of 2-seat WIG craft called NEW1. This research, which performs an aerodynamic experiment on a small model of NEW1, is also a part of the research and development program funded by the Royal Thai Navy. The objectives of the experiment are (a) to simulate the ground effect flow of the NEW1 model in a wind tunnel and collect the aerodynamic data for various flight attitudes and ground proximity conditions, and (b) to determine the effects of ground proximity to the aerodynamic characteristics of the NEW1 model. The test results were expected to help in understanding the aerodynamic aspect of wing in ground effect and be useful for further design of a WIG craft.

2. Experimental Method

This research focuses on how the proximity to the ground affects the WIG craft at different angles of attack and wing to ground distances. The results are obtained by performing wind tunnel tests on NEW1 model of 1:15 brief scale. The focused variables are written in Table 1.

| Parameter Variable | Value |
|--------------------|-------|
| Wing to Ground Distance Ratio H/C | 0.3, 0.4, 0.5, 1.0, 1.5 and 5.0 |
| Angle of Attack | −9 to 21 deg at a step of 3 deg. |

The experiment was conducted in the low-speed wind tunnel located at Department of Aerospace Engineering, Faculty of Engineering, Kasetsart University. The detail of equipment and experiment method are explained as follow.

2.1. Wind Tunnel

The wind tunnel used in this experiment is a close-loop type. The size of the test section is 1 m wide, 1 m height, and 3 m long powered by 70 kW motor. Contraction ratio of 4:1 provides the maximum velocity of 50 m/s at the test section. In this experiment, the velocity was controlled at 40 m/s and measured from Differential Pressure Sensor KIMO CP300 which consist of a Pitot-Static tube and a thermocouple installed at the inlet of the test section. During each test, the temperature of the air in the test section was measured and collected for the calculation of the air density.

2.2. Model

The test model was made of aluminum by a CNC machine as shown in Figure 1. The wing has its characteristics as follow:

| Wing Characteristics: |
|-----------------------|
| Wing Section: NACA 63-018 mod |
| Wing Span: 640 mm. |
| Wing Area 72,103 mm² |
| Taper Ratio 0.33 |
| Twist Angle 0° |

Figure 1. NEW1 WIG craft Model.
2.3. Ground Surface Model

The ground surface model used in this experiment is made of a plywood of 2.5 cm × 195 cm × 250 cm. The vertical position of the ground surface can be adjusted by rotating the four spiral pillars simultaneously with a stepping motor system. The installation of the ground surface and the test model is shown in Figure 2.

![Figure 2. Wing and Ground Models Installation Layout.](image)

2.4. Force Balance and Measurement

The test model is held by a supporting structure which can adjust for pitch, roll, and yaw angles. The supporting structure is also connected to 6-Degree of Freedom force balance, ATI Delta IP 65, which was used to measure 3 components of forces and 3 components of moments about the test model.

In the experiment, the values of forces, moments, atmospheric pressure, temperature, and the pressure of Pitot-Static were collected using Data Acquisition System NI Compact-DAQ 9220. Each measurement performed at the sampling rate of 100 Hz and the number of samples of 200 data per channel.

3. Results and Discussions

3.1. Without Ground Effect

The tests on the WIG craft at flight altitude out of ground effect provided the relations of the lift, drag and moment coefficients against the angle of attack as shown in Figure 3a. The results show that the critical angle of attack is at 12 degrees where the maximum lift coefficient (CL_{max}) is 1.6. The relation between the drag coefficient and the angle of attack is like a parabola curve at which the minimum point occurs at angle of attack of -6 degrees. The pitching moment coefficient at 25% chord has a negative slope which indicates decent longitudinal static stability.

3.2. CL and CD of the WIG Craft in Ground Effect

The test results of the WIG craft in ground effect with the flow velocity of 40 m/s are shown in Figures 3b and 4. The results show that the stall angles decrease from 12 degree to 9 degree when the WIG craft fly closer to the ground surface while the maximum lift coefficient (CL_{max}) is around 1.6 which is almost unchanged when comparing to the results of the WIG craft without ground effect (H/C = 5.0). In addition, the slope of the lift coefficient versus angle of attack graph will increase when H/C decreases which agrees with the theory of ground effect that when wing gets closer to the ground, the ground effect will reduce wingtip vortex as if the wing has a higher aspect ratio in which increase CL_{α}.

Figure 4a shows the effects of wing to ground distance to the lift coefficient. It was shown that at a lower altitude, the lift coefficient (CL) increases when H/C decrease. In the case of 0-degree angle of attack, the lift coefficient increases 15.7% when H/C decreases from 5.0 to 0.3. Furthermore, the
slope of the lift coefficient curves decrease with the distance between the WIG craft model and the ground.

Figure 4b shows the relation between the drag coefficient and the distance between the wing and the ground. The results show obviously that the drag coefficients of all cases decrease significantly when H/C decrease to 0.3. In the case of 0-degree angle of attack, the drag coefficient decreases 5.6% percent when H/C decreases from 5.0 to 0.3. The increase in lift coefficient and the decrease in drag coefficient consequently increase the lift to drag ratio tremendously by 33.4%.

![Figure 3](image1.png)

**Figure 3.** (a) Lift, drag, and moment coefficients at 25% C of the WIG craft without Ground Effect, (b) Lift coefficient of the WIG craft in ground effect.

![Figure 4](image2.png)

**Figure 4.** (a) Lift coefficient vs wing to ground distance, (b) Drag coefficient vs wing to ground distance.

### 3.3. CM and AC Location of the WIG Craft in Ground Effect

Important parameters which have effects on the static longitudinal stability of the WIG craft are the moment derivatives to its angle of attack (CM,\(\dot{\alpha}\)) and the location of aerodynamic centre (X,\( \omega \)) [6]. The relations of the moment coefficients about 25% chord and the angle of attack are shown in Figure 5. The slopes CM at 25% C curve at various vertical positions (H/C) are all negative indicating that
the WIG craft has positive favourable static longitudinal stability. However, the X intercept of the curve are at very high angle of attack which might cause unbalancing. To balance the WIG craft when flying, the CG may need to be located in front of 25% chord.

![Figure 5. Moment coefficient vs angle of attack](image)

Figure 5. Moment coefficient vs angle of attack (a) at $H/C = 5.0$, (b) at $H/C = 0.5$.

The locations of aerodynamic centers of each H/C case were determined by searching the longitudinal locations where the moment coefficient is constant. Figure 6 shows the effect of the proximity of the ground to the aerodynamic center location of the WIG craft. It was found that, when out of ground effect, the aerodynamic center is located at 34% $C$, and when the WIG craft fly closer to the ground the aerodynamic center move further aft, and it is located at 41.5% $C$ when $H/C = 0.4$.

![Figure 6. Effect of H/C to the Aerodynamic Center.](image)

Figure 6. Effect of H/C to the Aerodynamic Center.

4. Conclusions

This study experimentally investigated the aerodynamic characteristics of the WIG craft NEW1 model which is the first prototype designed by a Royal Thai Navy research team. It was found that the ground surface has significant effect on the WIG craft aerodynamics when the wing to ground distances are less than its mean chord. When the WIG craft fly within ground effect, the lift and moment coefficient were mostly increased while the drag coefficient tends to decrease, consequently the wing efficiency ($L/D$) increased up to 33.4%. The relations of the moment coefficients to the angles of attack showed that the WIG craft has positive longitudinal stability, but the aerodynamic centre trends to move aft toward the trailing edge when it fly closer to the ground. More details on the experimental results can be found in the research report [7].

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