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Numerical Investigations of Ground Effect of Helicopter UAV For Agriculture Application

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ABSTRACT: With objective of spraying pesticide, a classical Helicopter Unmanned Aerial Vehicle (HUAV) was designed, that included one main rotor which generates thrust against gravity and one second rotor in the tail to balance with the main rotor. The designed helicopter was affected based on the blade element theory. For spraying pesticide, HUAV usually flies only around 1-3m from the top of the plant. With such a small distance, effect of ground effect is inevitable. In this paper, the ground effect of HUAV was carried out using ANSYS software. HUAV was flied at 700 RPM of main rotor and 5781 RPM of tail rotor with altitude varying from 0.6D to 1.1D (D was diameter of main rotor). The aerodynamics characteristics of HUAV were estimated using computational fluid dynamic (CFD) tool in ANSYS software. Based on the aerodynamic results, the altitude of HUAV could be chosen to take advantage of the ground effect.

KEYWORDS: Helicopter; UAV; Ground Effect; Agriculture Application; ANSYS

INTRODUCTION

When an aircraft flies at a ground level approximately at or below the half length of the aircraft's wingspan or helicopter's rotor diameter, there occurs, depending on airfoil and aircraft design, an often-noticeable ground effect. This is caused primarily by the ground interrupting the wingtip vortices and downwash behind the wing. When a wing is flown very close to the ground, wingtip vortices are unable to form effectively due to the obstruction of the ground. The result is lower induced drag, which increases the speed and lift of the aircraft [1-2].

Helicopters in ground effect (IGE) are known to be one of the important flight modes for avoiding potential accidents of the vehicle. In ground effect, the rotor downwash appears compressed and spread out. One way of understanding how ground effect affects lift, is by considering that the static pressure underneath is increased and contributes to the lift. This means that less power is required to maintain a constant altitude hover. Therefore, accurate capturing of the tip vortex and the downwash induced by the rotor blades is essential for estimating the interaction between the ground and the rotor wake and for accurately predicting the performance of the rotor. However, the flow field around helicopters operating in ground effect is highly unsteady, turbulent, and viscous-dominated [3-4].

Assessments of helicopter rotor performance near ground were made previously by several researchers. The basic physical phenomenon of the ground vortex and its effect on the aerodynamic characteristics of the rotor were investigated in [5-6] by solving the CFD code based on unsteady 3D compressible Euler equations with a moving grid system with respect to the formation of ground vortex, the induced velocity distribution on the rotor disc.

Influences of non-uniform ground surface on IGE hover performance of a rotor were clarified in the reference [7], a numerical prediction method was developed by combining a free-wake method with a panel method, where the most important feature was the ability to determine blade flapping motions to be consistent with the deformed wake geometry. The ground surface beneath the rotor was substituted for quadratic panels with unknown ground vortex strength which were determined by virtue of the non-penetration conditions at the collocation points.

Wind tunnel measurements of the wake below and ahead of a model helicopter main rotor in simulated forward flight in ground effect were presented in [8-9]. Particle image velocimetry was used to investigate the structure of the wake, and it was observed that the moving ground had a remarkable effect on the flow; the wake was closer to the rotor and its size was reduced compared with the stationary ground case. The detailed distribution of vorticity within the wake was affected by the moving ground.

Boyd and Kusmarwanto reported an experimental study of the ground effect on a rotor wake when the rotor was operating at a height of less than one rotor diameter above the ground [10]. Particular attention was paid to how the rotor slipstream reacts to the oncoming wind and to the ground vortex generated when the wake eventually strikes the ground.

The research works of focused on aerodynamics characterization of main rotor in helicopter UAV [11]. This work used CFD tool in ANSYS CFX software to calculate the aerodynamics characteristics at hover flight mode with different blade pitch angles. The results were compared to experiment date in another research to validate numerical results. Then, the simulations were carried out in vertical flight mode and forward flight mode. The results showed that thrust and drag coefficient creased with increasing blade pitch angle.

There are many models of agricultural HUAV on the world. Manufacturers provide some information on how to use the aircraft so that it can achieve the best performance and achieve the efficiency in agriculture. Among the above guidelines, some HUAV recommend users to fly at altitude from 1 to 3 m. In this altitude, HUAV will be affected by ground effect.

METHODOLOGY

With the aim of IGE, this work carried out steady aerodynamic problem with help of ANSYS software. There were two rotated problems need to solve at the same time: one of main rotor and other of tail rotor. The HUAV was at hovering flight mode with at 700 RPM of main rotor and 5,781 RPM of tail rotor. The influence of IGE was estimated by varying the altitude of the HUAV from 1 to 3 m.

HUAV model

HUAV model was designed with 15 kg useful load and 68 kg in total weight. This HUAV model was classical helicopter type that included one main rotor and one tail rotor (Figure 1).

- ✓ Main rotor: had two blades with 3.5 m in diameter, 0.13 m in chord length, NACA0015 in airfoil, and 1.0 in taper ratio;
- ✓ Tail rotor: was the propeller of P60KV340 motors with 0.508 m in diameter and 0.152 m in pitch;
- ✓ Fuselage: had 2.611 m in length, 0.509 m in width and 1.165 m in height.

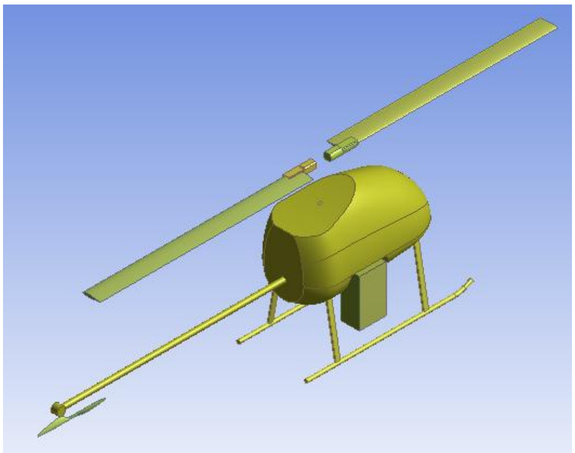


Figure 1. HUAV model

Computational domain

Computational domain was identified in Figure 2. It included two dynamic domains as shown in Figure 2a (one of main rotor with 3.5 m in diameter and other of tail rotor with 0.508 m in diameter) and static domain as shown in Figure 2b (the rest of computational domain with dimension of 8Dx(4D+H) , where D was diameter of main rotor and H was altitude of HUAV that varied from 1 to 3 m equivalent to 0.6D to 1.1D).

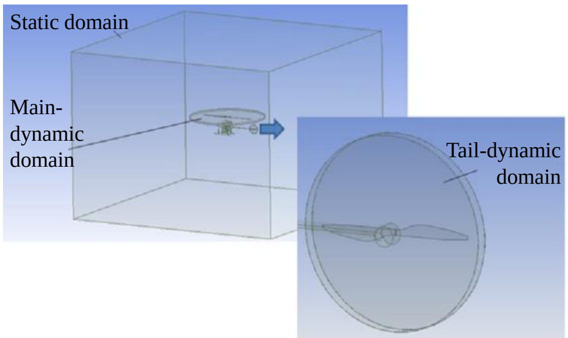
Meshing grid

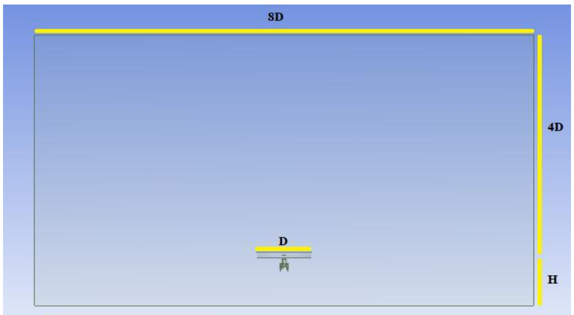
The computational domain was meshed with $3.0*10^6$ unstructured elements with Skewness number of 0.22 and Orthogonal number of 0.75 (Figure 3).

Boundary conditions

For hovering flight, the boundary conditions included:

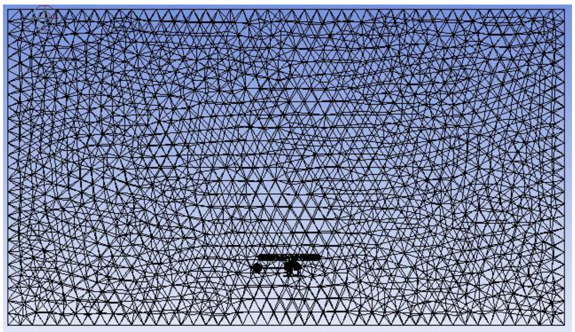
- ✓ Velocity inlet was zero;
- ✓ Other faces were ambient pressure;
- ✓ Main rotor was rotated at 700 RPM;
- ✓ Tail rotor was rotated at 5,781 RPM.



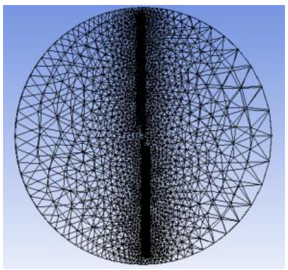


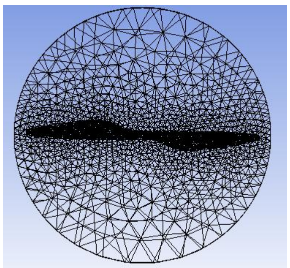
a. Dynamic domain   b. Dimension

Figure 2. Computational domain



a. Computational domain





b. Main rotor   c. Tail rotor

Figure 3. Meshing grid

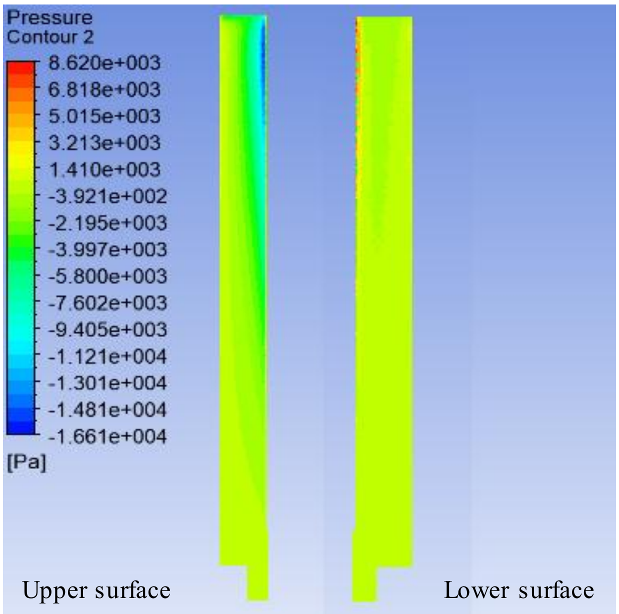
Turbulent model

The k-ε standard turbulent model was chosen due to its stability and convergence. This model is the most widely used and validated turbulence model with applications ranging from industrial to environmental flows, which explains its popularity. It is usually useful for free-shear layer flows with relatively small pressure gradients as well as in confined flows where the Reynolds shear stresses are most important. It can also be stated as the simplest turbulence model for which only initial and boundary conditions needs to be supplied.

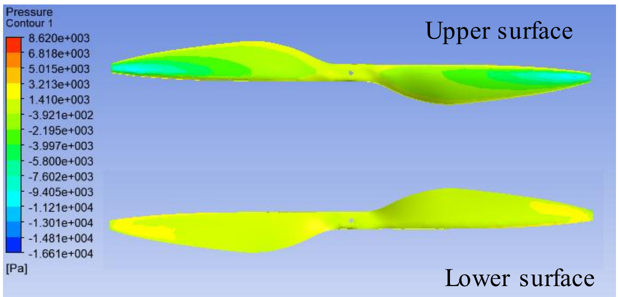
RESULTS

Aerodynamic of HUAV

The distribution pressure on upper surface was less than that on lower surface for both main rotor (Figure 4a) and tail rotor (Figure 4b), which created lift force for rotorcraft. The pressure was varied in following radius of blade. From the root to the tip, the upper surface pressure reduced, while lower surface pressure increased. Therefore, the lift force was gradually increased from the root to the tip. The pressure of upper surface of main rotor was minimum at 0.7R (R was radius of main rotor).

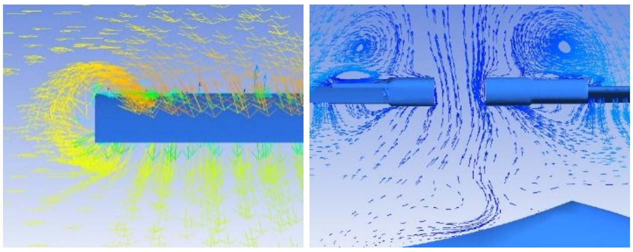


a. Main rotor

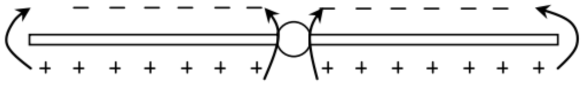


b. Tail rotor

Figure 4. Distribution of pressure



a. Tip of main rotor b. Root of main rotor



c. Real main rotor [1]

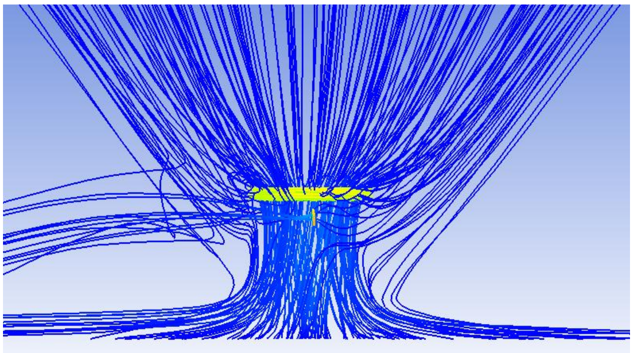
Figure 5. Appearance of vortices

Velocity was complex at tip region (Figure 5a) and root region (Figure 5b) as remarked in Reference [1] (Figure 5c). It seemed that the tip vortex and root vortex (Figure 5) caused a loss of thrust. That could be one of the main reasons of different between theory and simulation.

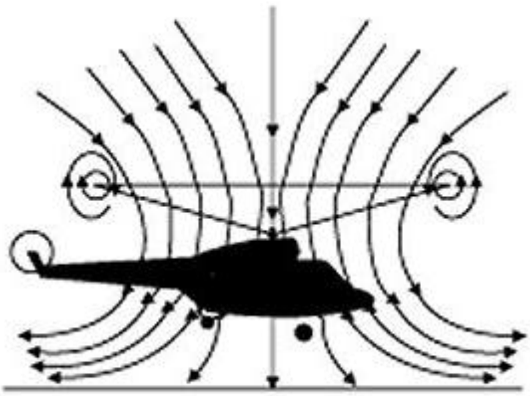
It could be concluded that the induced velocity varied according the radius. The induced velocity was maximum at reference station (at 0.7R) and minimum at root and tip station. This remark was good agreed with reference [1].

The streamline of HUAV model was presented in Figure 6a. The streamline was changed compared to the model that included only main rotor [7]. Here, a part of the flow going into the main rotor was influenced by the outflow of tail rotor. This also more or less affected the thrust that induced by main rotor.

This streamline had same tendency as streamline in ground effect (Figure 6b, [1]), that had a small tip vortex and outflow from main rotor was blocked by the ground and out from the area of main rotor.



a. HUAV model



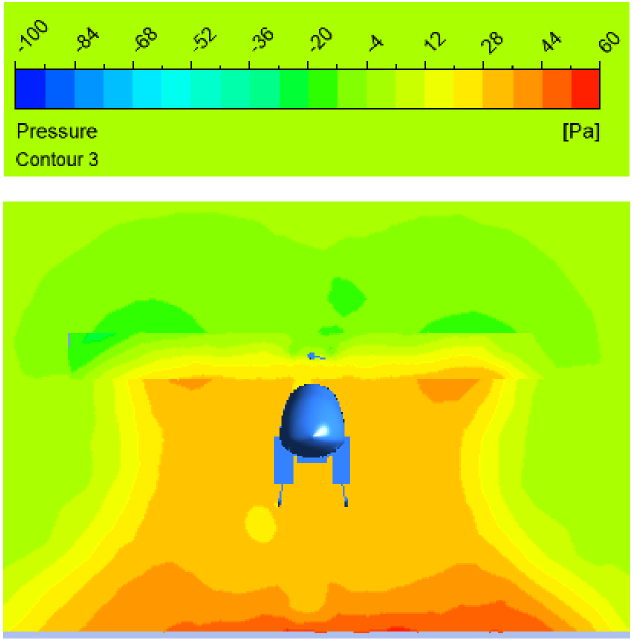
b. In ground effect [1]

Figure 6. Streamline

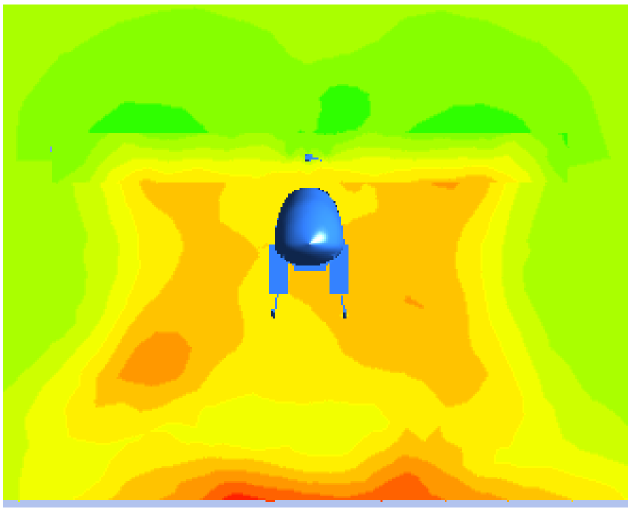
Ground effect of HUAV

Influence of ground effect was estimated by varying altitude of HUAV from 1 to 3 m equivalent to 0.6D to 1.1D. Figure 7 presented pressure distribution at cross section perpendicular to main rotor.

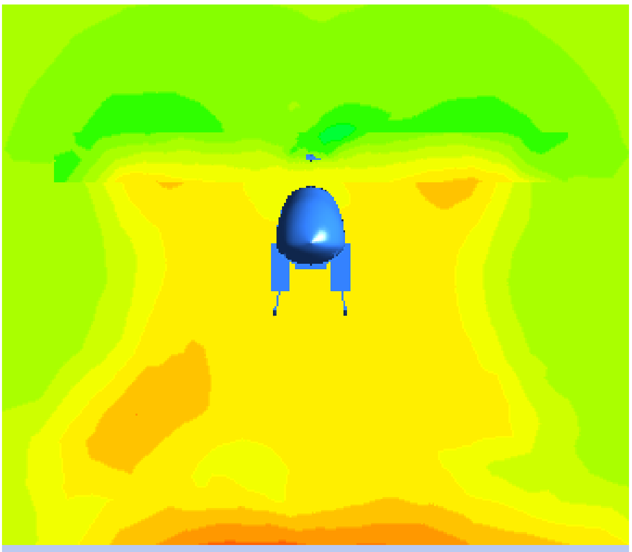
At altitude 0.6D, pressure of downwash airflow was high and maximum near the ground (Figure 7a). Downwash airflow was dissymmetric due to the effect of tail rotor. Pressure at the same side of tail rotor was higher than that at the other side (left side of Figure 7a). The HUAV was in ground effect.



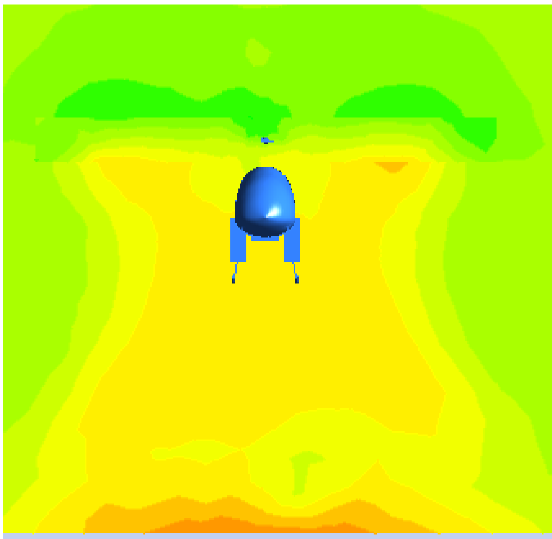
a. H = 0.6D



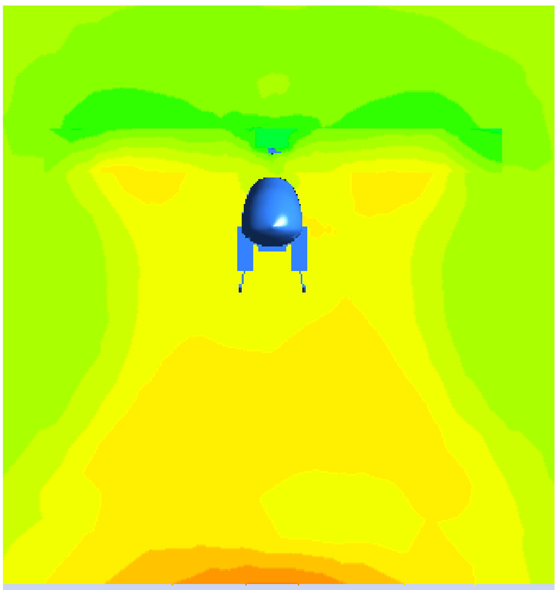
b. H = 0.7D



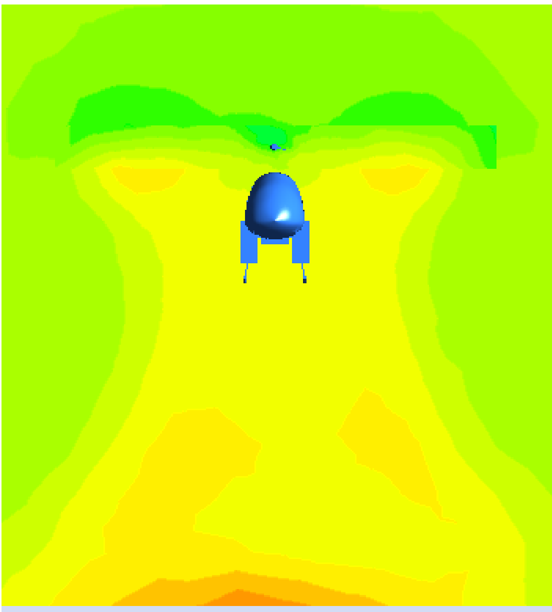
c. H = 0.8D



d. H = 0.9D



e. H = 1.0D



f. H = 1.1D

Figure 7. Distribution of pressure at different altitudes

Lower pressure of main rotor was reduced when increasing altitude of HUAV from 0.6D to 1.1D (Figure 7). High pressure region near the ground reduced. The dissymmetric of downwash airflow seemed almost disappeared when altitude of HUAV increased to 1.1D.

To clarify the impact of the ground effect, the thrust forces of main rotor at different altitude were estimated and presented in Figure 8.

Thrust was maximum of 852 N at altitude 0.6D. This value reduced with increasing of altitude until altitude 1D. From altitude 1.0D, thrust increased. It could be concluded that HUAV was in ground effect with altitude from 0.6D to 0.9D and out of ground effect with altitude from 1.0D to 1.1D. These remarks were in good agree with reference [1] that IGE often occur in ranges of altitude smaller than the diameter of main rotor (H < D).

Therefore, with designed HUAV, the recommended operating altitude was from 0.6D to 0.9D (about 1m - 2m).

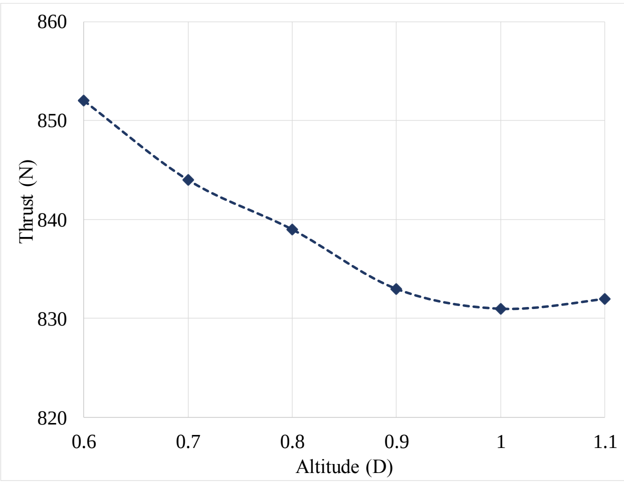


Figure 8. Influence of IGE

With the benefits of ground effect, the specific cases using ground effect are as follows:

- ✓ The load is too high and exceed the design load. So, to continue flight, HUAV would use in ground effect;

- ✓ For airport at mountain, the air density reduces that reduces the thrust of main rotor. So, to achieve the required thrust force, HUAV would use in ground effect;
- ✓ One way of understanding how ground effect affects lift, is by considering that the static pressure underneath is increased and written to the lift. This means that less power is required to maintain a constant altitude hover.
- ✓ The effect of the air cushion has a positive effect on the stability of the aircraft. When the main rotor is tilted in some direction, that part is closer to the ground, the traction increases and the tissue- balanced enamel.

CONCLUSION

In this research, the ground effect was successfully solved by using ANSYS software. The major results were:

- ✓ Simulation results were a good accord with theory.
- ✓ The flow field at the tip and the root of rotor was complex and that could cause a loss of thrust. Therefore, the profile of rotor at the tip and the root could be improved to gain the thrust.
- ✓ Ground effect was found out at altitude less than diameter of main rotor.

It is necessary to validate these numerical results with experimental results or other numerical results in the future.

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