The Effect of MultiCopter Drone's Ground Effect on Battery Efficiency

Seong-Seop Hwang[1], Jin-Sung Kim[2], Soo-Yun Kim[3], Dong-Hyung Lee[*4]
[1,2,3]PhD Student, Department of Industrial & Management Engineering, Hanbat National University, 125, Dongseo-daero, Yuseong-gu, Daejeon, 34158, Republic of Korea
[* 4] Professor, Department of Industrial & Management Engineering, Hanbat National University, 125, Dongseo-daero, Yuseong-gu, Daejeon, 34158, Republic of Korea

Abstract.
BACKGROUND/OBJECTIVES: In the case of helicopter, the ground effect generated by down-wash during hovering saves fuel and reduced power through stable hovering. However, in the case of the multicopter drone, it is questionable whether the ground effect will appear positively. Since the ground effect of multicopter drone is closely related to battery efficiency, it is necessary to investigate how the ground effect of multicopter drone affects battery efficiency in order to increase the efficiency of multicopter drone education.
METHODS/STATISTICAL ANALYSIS: Among the ultra-light unmanned aerial vehicle multicopter drone, we experimented with an 8-winged octocopter and a 4-winged quadcopter. The place we experimented with was conducted in an indoor space, where there was no wind, and the ground was solid and flat, and under the conditions of no external influence. Experimental method is to test 30 times each at 3 flight altitudes (1/2, 1/1, 2/1 of the rotor diameter) by hovering for 5 minutes with fully charged batteries installed in the Octocopter and Quadcopter drones. In every experiment, the remaining voltage value of the battery was recorded, and after recharging the battery, it was mounted on a drone and tested again. The recorded results were converted into descriptive statistics for power consumption and the homogeneity test of the variance was verified through a one-way ANOVA. Experimental conclusions were drawn by Scheffe's post-hoc test.
FINDINGS: The ground effect of a helicopter was found to operate with reduced power at altitudes less than 1 times the rotor diameter, but it was found that multicopter drone are related to the size of the drone and thus increase or decrease the efficiency of the battery. In the case of the large octocopter among multicopter drone, the battery efficiency increased in the same way as the helicopter ground effect, and the result was that it can fly a little longer when flying close to the ground. On the other hand, the quadcopter, a small and light drone, uses a lot of electric signals to maintain hovering stability, resulting in increased battery consumption. As a result, the ground effect of the quadcopter was different to that of the Octocopter. That is, the effect of the multicopter drone's ground effect on the battery efficiency could vary depending on the size and control system of the drone. Therefore, it is judged that it is advantageous to use the multicopter drone hovering education as a large drone as much as possible.
IMPROVEMENTS/APPLICATIONS: When doing hovering education of the multicopter drone, it is advantageous a larger drone is used. In the future, it is needed the research about the battery efficiency problem depending on the size of the drone.

Keywords: Helicopter, Hovering, Ground Effect, Multicopter Drone, Battery.

1. INTRODUCTION

Drones, commonly referred to as unmanned aerial vehicles, are divided into fixed wing aircraft and rotating aircraft, and are capable of automatic flight and remote control by radio waves without a pilot [1]. The rotating aircraft was manufactured in the form of a Tilt rotor, Co-axial, and Multi-rotor unmanned aerial vehicle. It used to be called UAV (Unmaned Air Vehicle), but now it is collectively called UAS (Unmaned Air System). The first drone was a bomb-loaded aircraft called the "Sperry Aerial Torpedo" manufactured in the United States in 1917. And then 1930s, the British Navy developed the de Havilland DH-82B Queen Bee for training anti-aircraft gunners. The name of this unmanned aerial vehicle was called 'Queen Bee'[2]. And now it is called a drone, it is used in various in many fields. In this paper, to use in hovering education of multicopter drone, we study the effect of the ground effect on battery efficiency and investigate through experiments whether this effect can extend the hovering time of multicopter drone.

2. GROUND EFFECT

2.1. GROUND EFFECT OF HELICOPTER

In all aircraft, the effect on the aircraft due to the air flow that occurs when flying near the ground is called the ground effect, and it can fly with a power less than the normal power of the aircraft [3]. In particular, according to the physical laws, the helicopter is very efficient at heights less than 1 times the rotor diameter when hovering, and hovering using the actual ground effect [4]. In other words, the ground effect is due to the increase in the efficiency of the rotor (wing) system due to the interference of air flow, the relative wind of the incoming air becomes more horizontal, the lift vector becomes more vertical, and the induced drag decreases, thereby reducing the power of the helicopter. However, the pilot's hovering over tall grass, trees, bushes, rough terrain, or water is less power efficient than on hard ground. This phenomenon can be explained by induced flow and vortex formation [5]. In Figure 1 shows the result of hovering by various types of helicopters while the ground is solid. The ground effect of the helicopter can be confirmed that the power decreases to a height of less than 1 times the rotor diameter.

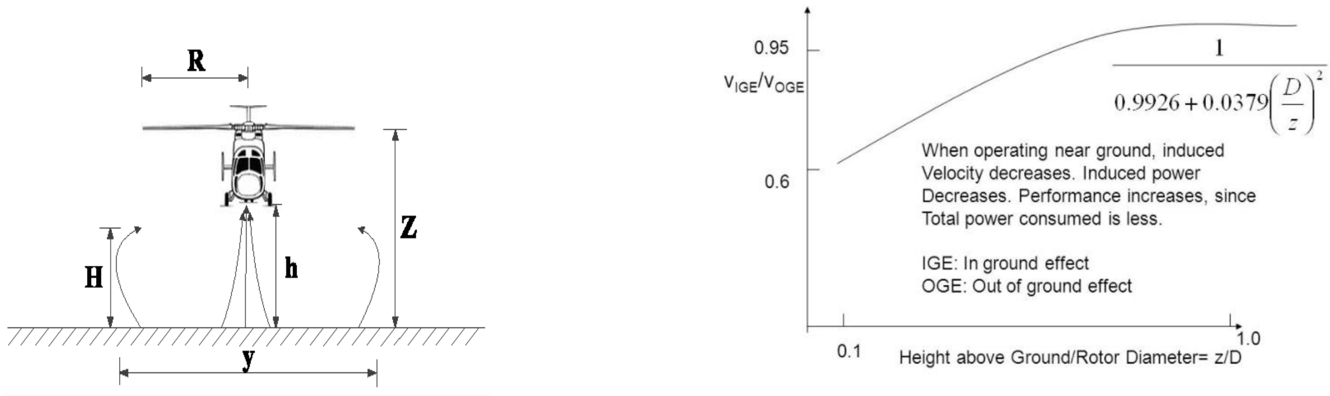

Figure 1. Relationship between helicopter hover height and ground effect [6,7]

When the helicopter is hovering, the airflow can be viewed with a wind tunnel test. As shown in Figure 2(b), the ground effect occurs when it is within 1 times of the rotor diameter (In Ground Effect). And as shown in Figure 2(a), when the rotor diameter is more than 1 times, it can see that the ground effect does not occur (Out of Ground Effect) [8].

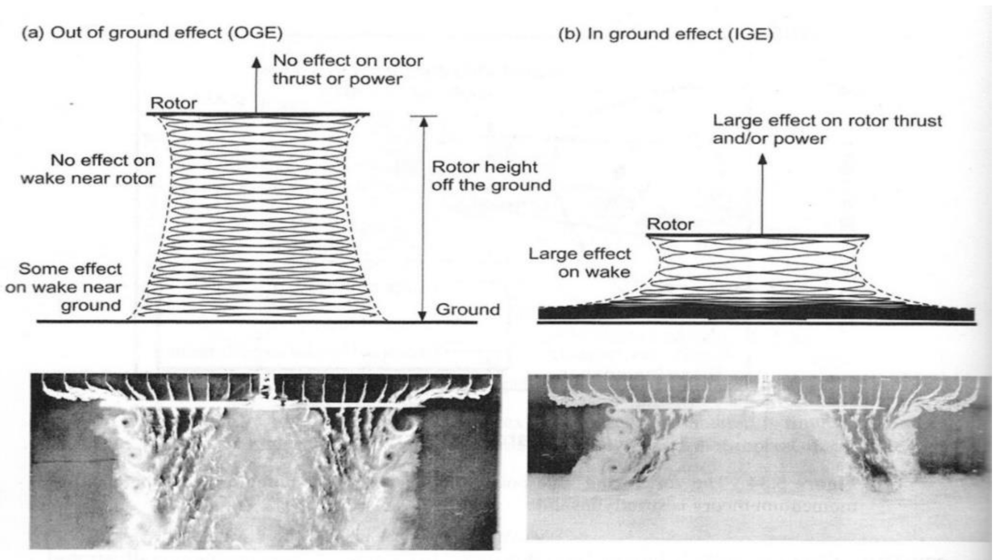

Figure 2. The behavior of the wake from a hovering rotor (Flow visualization photos courtesy of Sikorsky) [8]

In other words, when hovering is performed while the air flow is close to the ground, the air flow collides with the ground and is bound to push the helicopter rotor from the bottom to the top. That is, the upper thrust is increased, which reduces the power of the helicopter. Today with the use of high-speed computers, the simplified assumptions can be more delicate, and the confidence level in the calculations is increased but not yet to 100%. This is because it is very difficult to experimentally measure the velocity in and around a rotor in order to get data with which the computer results can be correlated. Some progress has recently been made through the uses of a piece of sophisticated measuring equipment known as a laser velocimeter [9].

2.2. GROUND EFFECT OF MULTI-COPTER DRONE

In Figure 3 below shows a CFD (Computational Fluid Dynamics) simulation showing the ground effect of a multicopter drone. The simulation was driven using a simplified model of a quadcopter hovering at an altitude of one the rotor diameter in the ground plane. The rotor was modeled with a constant velocity value in the area of the rotor, that is, the rotation of the rotor was not simulated. It is expressed as the average value of the air velocity measured in the PQUAD quadcopter rotor hovering at a constant speed, and the central part is modeled as a central body. As shown in Figure 3, the air flow is shown in the cross-sectional view, and the air flow at the ends of rotor 1 and 3 spreads outward, while the central part between the two rotors interacts with the central body parallel to the ground. This interaction occurs due to the ground effect and increases the lift and decreases the power. And it can also be seen forming a vortex ring. Such eddies also appear in helicopters, mainly caused by drag at the tip of the rotor, reducing power, and multicopter drone are also the cause of reducing thrust.

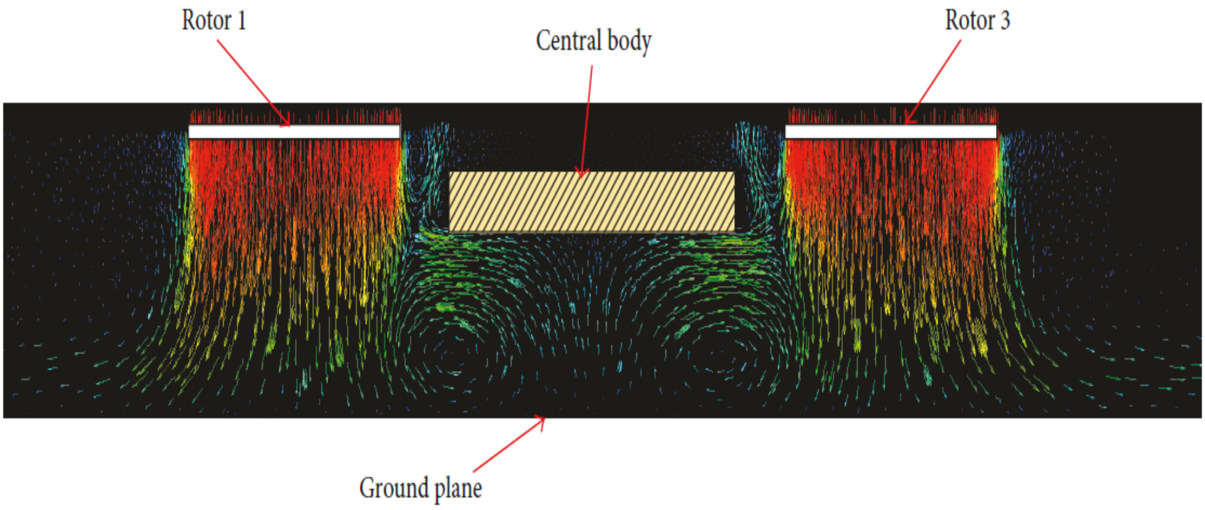

Figure 3. CFD simulation of a quadcopter hovering in ground effect [10]

3. RESEARCH RESULTS

3.1. OCTOCOPTER'S GROUND EFFECT RESULTS

Among the multicopter drone, the Octocopter, which consists of 8-wings, can generate a lot of lift, which increases the cargo load, frame size, and battery capacity, making it difficult to carry and store. The first octocopter tested was the discontinued KA-801E, with maximum take-off weight of 25 kg, a body size of 210*51 cm, body weight of 14.2 kg, three 16,000 mA batteries, and flying ability of 30 to 35 minutes. Usually after a 20-minute flight, the battery is charged to maintain battery performance and then re-flight. In order to maintain the same experimental conditions, a fully charged 99% battery is installed in an indoor space with a solid and flat floor, a constant temperature and no wind. Outdoors, the Global Navigation Satellite System (GNSS) can be used to determine location and accurate data, but indoors, transmission and reception are cut off, resulting in an error in which the location cannot be accurately recognized. So, we had to experiment with turning off the GPS transceiver when flying a multicopter drone indoors. The first experiment records the remaining battery voltage after stably hovering 30 times each for 5 minutes at 3 altitudes: 1/2, 1/1, 2/1 based on the diameter of the rotating surface of the Octocopter 210 cm. In Figure 4 shows whether the octocopter's ground effect is effective for battery performance.

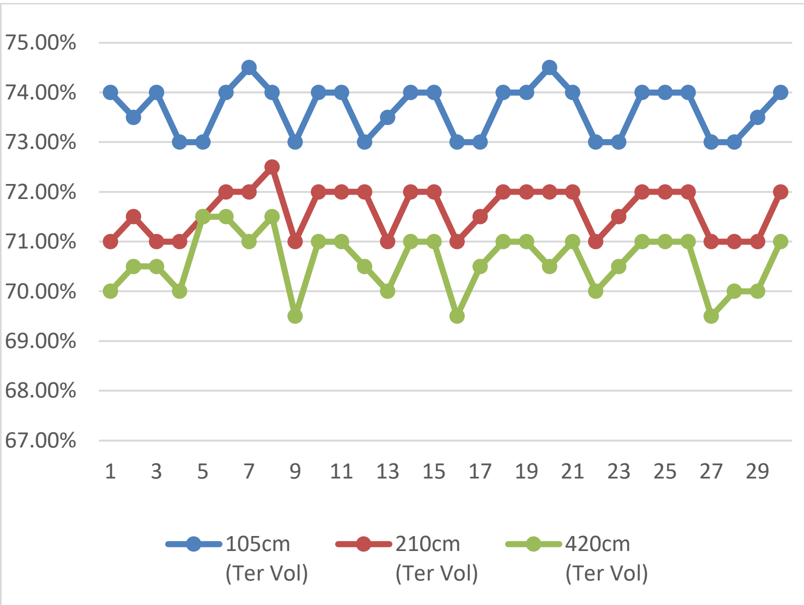

Figure 4. Remaining battery voltage after hovering for 5 min at 99% fully charged battery condition

As a result, the ground effect was generated according to the hovering altitude of the octocopter, and the voltage value was different for each altitude. Based on this result, the power consumption was converted into descriptive statistics, and the homogeneity of variance was tested. One-way ANOVA was conducted to verify that the average of the power consumption according to the hovering altitude showed a significant difference. As a result, as shown in Table 1, the power consumption of the octocopter ($F=255.709$, $p<.01$) was significantly different.

Table 1: The result of One-Way ANOVA (Analysis of Variance)

Category	SS	df	MS	F-value	p-value
Inter group	144.706	2	72.353	255.709	0.000
Intra group	24.617	87	0.283		
Total	169.322	89			

In addition, since the average of the power consumption differs according to the hovering altitude of the octocopter, a post-hoc test analysis of the Schffe's according to the hovering altitude was performed. As a result, as shown in Table 2, the power consumption of 210 cm was lower than that of 420 cm, and 105 cm was lower than that of 210 cm. In other words, at the three hovering altitudes of the Octocopter, the power consumption was the least at 105cm, and the battery efficiency of the ground effect was the highest.

Table 2: The result of Scheffe's post-hoc test

Criterion	Comparison target	Mean difference	p-value
105cm	210cm	-2.033^{*}	0.000
	420cm	-3.050^{*}	0.000
210cm	105cm	2.033^{*}	0.000
	420cm	-1.017^{*}	0.000
420cm	105cm	3.050^{*}	0.000
	210cm	1.017^{*}	0.000

3.2. QUADCOPTER'S GROUND EFFECT RESULTS

Among the quadcopter consisting of four wings, an educational long fly drone was used as the second experiment. The size of the drone is 28*11 cm, and the battery is 15 units of 1,800 mA. This battery can fly for about 10 to 12 minutes. In order to maintain the same experimental conditions, a fully charged 99% battery was installed in an indoor space with a solid and flat floor, a constant temperature and no wind. This experiment records the remaining voltage of the battery after stable hovering for 5 minutes each 30 times at 3 altitudes such as 1/2, 1/1, 2/1 based on the diameter of the rotating surface of the quadcopter 28 cm. In Figure 5 shows whether the quadcopter's ground effect is effective for battery performance or not.

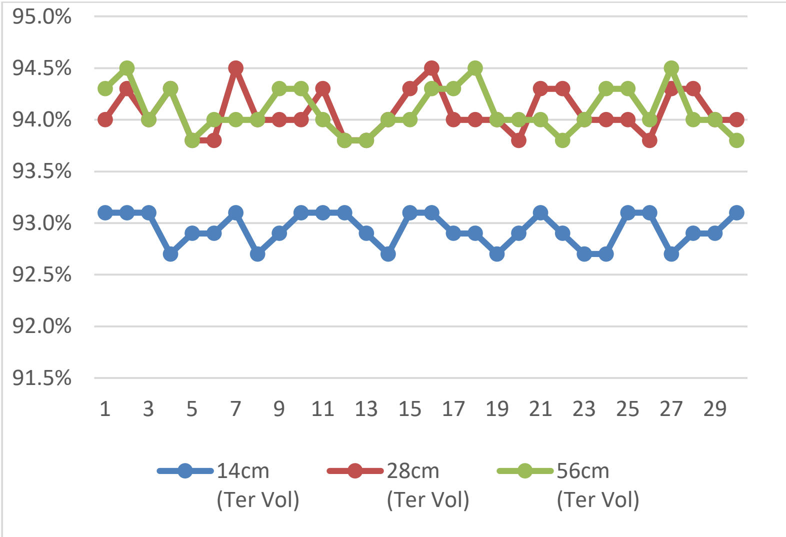

Figure 5. Remaining battery voltage after hovering for 5 min at 99% fully charged battery condition

As a result, the ground effect was generated according to the hovering altitude of the quadcopter, resulting in a difference in voltage value for each altitude. Based on this result, the power consumption was converted into a descriptive statistic and a homogeneity test of variance was conducted. One-way ANOVA was conducted to verify that the average of the power consumption according to the hovering altitude showed a significant difference. As a result, it was found that the power consumption of the quadcopter ($F=331.636$, $p<0.01$) showed a significant difference as shown in Table 3.

Table 3: The result of One-Way ANOVA (Analysis of Variance)

Category	SS	df	MS	F-value	p-value
Inter group	26.229	2	13.114	331.636	0.000
Intra group	3.440	87	0.040		
Total	29.6690	89			

Scheffe's post-hoc test analysis was conducted to determine which altitude the difference was at which altitude, since the average of the power consumption differed according to the hovering altitude of the quadcopter. As a result of post-hoc test analysis, there was no difference between the heights of 28 cm and 56 cm, but there was a difference between 14 cm and 28 cm and 14 cm and 56 cm. As shown in Table 4, among the three hovering altitudes of the quadcopter, the power consumption was the most at the altitude of 14cm, and there was no difference between 28cm and 56cm. As a result, it was found that the ground effect of the educational quadcopter long fly rather reduced the efficiency of the battery. This suggests that the size and weight of a multi-copter drone can be a factor for ground effect.

Table 4: The result of Scheffe's post-hoc test

Criterion	Comparison target	Mean difference	p-value
14cm	28cm	1.133^{*}	0.000
	56cm	1.157^{*}	0.000
28cm	14cm	-1.133^{*}	0.000
	56cm	0.023	0.902
56cm	14cm	-1.157^{*}	0.000
	28cm	-0.023	0.902

3.3. FURTHER IMPROVEMENTS TO THE RESULTS

While flying a multicopter drone indoors, it was difficult to maintain a constant hovering altitude because it was not able to properly transmit and receive location information while turning off the GPS transceiver. So, in the next experiment and research, we plan to apply indoor location detection technology using indoor beacons among the methods to be applied to solve this, and this beacon can operate at low power and low cost. And it links location information with Bluetooth 4.0 and Android applications. We can get accurate data values by installing beacons [11]. In addition, for accurate data transmission, it will be improved so that it can be experimented with a multicopter drone applied with a route search and a routing technique to reduce disconnection of the set transmission path [12].

4. CONCLUSION

In this study, two multi-copter drones were tested to find out the effect of the multicopter's ground effect on battery efficiency, and one-way ANOVA was conducted to verify the results. As a result, it was confirmed that the ground effect of Octocopter among multicopter like helicopter increases battery efficiency by reducing power. Therefore, Octocopter can extend hovering training time compared to other drones. However, the educational long fly quadcopter turned out to be the opposite. The long fly quadcopter has a small, lightweight drone, and poor maneuverability, so at very low altitudes, it hovered unstable due to down-wash obstruction. This increased battery power consumption by using electric signals of many controls for stable hovering by the operator. In the future, based on this result, it will be necessary to experiment to see if the battery efficiency due to the ground effect increases when the size of the multicopter drone is over what size.

5. REFERENCES

1. Industrial policy Research, “Global market and technology trends and safety management and regulatory trends forecast for the drone unmanned aerial vehicle industry”, IP Research Center, 1 Jul 2015, pp. 229.
2. http://www.vintagewings.ca/VintageNews/Stories/tabid/116/articleType/ArticleView/articleId/484/The-Mother-of-All-Drones.aspx
3. R. W. Prouty, “Helicopter Aerodynamics”, Phillip pub co Publishers, 1 Jun 1985. Part 2, chapter 9.
4. The Korean Society for Aeronautical & Space Sciences, “Introduction to Aeronautics & Astronautics”, Kyungmun Publishers, 2 Mar 2020. Part 3, chapter 10.
5. FM 3-04.203, “Fundamentals of Flight”, U.S. Headquarters Department of the Army Washington, D.C. 7 May 2007; pp.1-36. Available from: https://fas.org/irp/doddir/army/fm3-04-203.pdf.
6. https://www.semanticscholar.org/paper/Visual-Simulation-of-Ground-Effect-Zheng-Zhang/3d1273aa1795a7e866c0cdf9a4cb1c9491d23a7c/figure/1
7. https://slideplayer.com/slide/3493194/#.X8mKFqIcxko.gmail/ppt, p35.
8. https://aviation.stackexchange.com/questions/47583/what-are-the-airflow-patterns-of-a-helicopter-when-operating-in-ground-effect
9. https://www.rotorandwing.com/2017/07/26/ray-prouty-progress-helicopter-aerodynamics
10. Pedro Sanchez-Cuevas, Guillermo Heredia, and Anibal Ollero. International Journal of Aerospace Engineering Volume 2017, Article ID 1823056, pp.17. DOI:10.1155/2017/1823056
11. Sung-Jin Jeoung, Bong-Hyun Kim. Journal of Next-generation Convergence Technology Association. Mar 2019; Vol.3, No.3, pp. 94-99. DOI:10.33097/JNCTA.2019.03.03.94.
12. Min Hee Oh, Seung-Jung Shin. Journal of Next-generation Convergence Technology Association. Apr 2020; Vol.4, No.4, pp. 388-393. DOI:10.33097/JNCTA.2020.04.04.388.