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Numerical Investigation of Acoustic Wave Generation from Individual Propellers of a Multicopter

Kim, Minwoo[1]
Korea Aerospace Research Institute
169-84, Gwahak-ro, Yuseong-Gu Daejeon, 34133, KOREA

Lee, Bosung[2]
Korea Aerospace Research Institute
169-84, Gwahak-ro, Yuseong-Gu Daejeon, 34133, KOREA

ABSTRACT

In this study, we try to investigate noise emissions of a multicopter during flights. To identify noise emissions from individual propellers of a multicopter, we had several test flights to measure RPMs of propellers. From the experimental thrust and RPM variation information of propellers, we took numerical simulations for aerodynamic and aeroacoustic characteristics for various flight conditions. We compared noise emissions of individual propellers when a multicopter is in hover with various weights and forward flight with various speeds.

Keywords: Propeller Noise, Multicopter
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

In recent years, electric propulsion system has been applied to automobiles and aircraft due to technological advances in electric motors and batteries. The electric propulsion systems has a simple structure and does not require a mechanical power transmission component as compared with the conventional engine system, so that it can be applied to aerial vehicles such as multicopters requiring a plurality of propulsion parts. Since the flight control mechanism of the multicopters is simpler and more robust than the conventional helicopters, the use of multicopter on the aerial photography has increased. In the field of agriculture, infrastructure inspection, and delivery service other than aerial photography, demand for multicopter is increasing, and the economic impact of unmanned aerial vehicles including multicopter is expected to increase gradually 82B$ until 2025[1]. The UTM(UAS Traffic Management) and UAM(Urban Air Mobility) programs show that the operating environment of multicopter is moving from suburban to urban areas and a small number of operations to a large number of operations[2].

[1] mwkim@kari.re.kr
[2] gotocloud@kari.re.kr

As the number of operations of multicopter is increased and it is expected that operation area is moved to the vicinity of the urban area, the noise generated from the propeller is expected to become a kind of new sources of annoyance [3]. To analyse the community noise due to multicopters, it is necessary to analyse the noise generated by propellers. In this regard, research related to multicopter noise is mainly performed by measuring and single propeller noise of multicopters [4,5].

In this paper, we consider multi-copter noise generation process considering practical flight operation of multi-copter. For this purpose, we build a multi-copter with 8kg take-off weight. And, we perform a flight test according to various flight conditions for dummy weight and forward flight speed, and we collect the measured RPM data of each propeller. We analyse propeller noise data from individual motor based experimental flight environment, and evaluate noise level contours of ground surface under multicopter.

2. EXPERIMENT SETUP

2.1 Building Multicopter for Flight Tests

Ideally, the thrust distribution of the multicopter should be symmetrical with respect to the heading direction of the vehicle. In the case of a practical multicopter, however, the position of the C.G. deviates from the geometric center depending on the arrangement of the flying equipment (FCC, GPS device, radio communications) and the location of the battery. In addition, the electrical characteristics of the electric motor also vary slightly due to differences in the mechanical arrangement (magnet allocation and winding) of the electric motor. As a result, the rotating speed of each propeller during the actual flight is affected by the deviated location of the C.G., the difference in the thrust due to the characteristics of the motor, and flow disturbance such as external wind or induced wake.

In order to experimentally find the individual RPM of a multicopter, we built a multicopter vehicle and performed a flight test. In consideration of the flight test conditions, we built a multicopter with 8kg takeoff weight, and detailed specifications are written in Table 1. FCC of typical multicopter does not record a logging data for the mechanical RPM of each individual motor, so we employed separate measuring instruments for finding RPMS. We used the elogger by Eagle-Tree to measure the RPM using hall sensor externally mounted on motor and to collect the PWM signal from the FCC. Using the FCC logging data about individual motor's PWM signal and the each elogger's PWM signals, the individual RPM measurement data were synchronized. (Fig. 1)[6]

2.2 Flight Tests

Flight tests were conducted for hovering and forward flight conditions, and detailed condition of the flight tests are written in Table 2. The condition for hovering flight tests was flight with Position Hold mode without pilot intervention at 10 m AGL (above ground level). The conditions for the forward flight test were an automatic flight of several round trips between waypoints prescribed in the GCS. The velocity during forward flight was based on FCC 's GPS speed log.

Figure 2 shows the RPM log of the individual motors for hovering condition. Figure 3 shows the RPM log of the individual motors during forward flight. In actual flight, RPM changes every moment due to intervention of FCC, but we chose the average value of RPM log to determine representative value for numerical analysis. (See Table 3)

3. Numerical Analysis

3.1 Approach

Since the shape of a commercial propeller of a multicopter is not disclosed, the propellers used in the flight test are directly scanned via 3D scanner. The sectional airfoils and twist angles of the propeller are extracted from the three - dimensional model. (Figure 4). The aerodynamic analysis of the propeller is carried by free wake panel method with the viscosity and compressibility correction, and then, aeroacoustic data from propeller is obtained by applying Farassat's formulation 1A. [7,8]

In the case of a rotor or propeller in which the rotation speed is fixed, such as a helicopter or turbo-prop aircraft, the phase effect depending on the position of the propeller affects the noise level. In the case of multicopter, however, rotation speeds are varying during flight. We evaluate individual noise levels on observer points and compared major contribution of noise sources.

3.2 Numerical Investigation

The numerical analysis is performed according to the conditions of hovering flight tests and forward flight test (H1, H2, F1). The input values of each propeller are determined according to the individual motor location and the rotating speed which are obtained by flight tests. The observer points are distributed on a plane about 2.3 m (approximately 10 R distance of propeller) under a vehicle. (Figure 5).

Figure 6(a) illustrates noise levels under H1 Case. Since there is little difference in the rotational speeds of individual propellers, no significant change can be identified by the difference in rotational speed of each propeller. As shown in Fig. 6(b), the difference between the maximum rotation speed (M3, 4424) and the minimum rotation speed (M1, 3612) is large in the H2 case with heavier duty comparing to H1 case. So, noise emitted form M3 propeller is higher than that of M1 propeller. In the case of the forward flight (F1 case), the rotational speed of the front propeller(M1) is lower than that of the rear propeller(M4) in order to maintain multicopter's attitude. So, it is confirmed that the noise level near rear propellers is higher than front propellers

In the actual mission situation, the payload equipment such as the EO/IR camera is mounted on the front-lower part of multicopter. So, C.G. of vehicle deviates from the geometric center. It results in uneven thrust distribution and eventually the asymmetrical noise level. Moreover, the attitude angle of the vehicle is inclined to forward direction during the forward flight, and thus, the asymmetrical noise level distribution can be found due to the difference in thrust between the front and rear propellers.

4. CONCLUSIONS

We built a multicopter testbed to investigate the noise characteristics of the multicopter during flights. We measured rotation speed of each motor and we performed numerical analysis for estimating noise levels generated by the individual propellers of the multicopter. Through numerical investigations we found that the noise distribution around multicopter during hovering flight is not symmetric when multicopter is under heavier duty, and noise level at rear position of multicopter is higher than front position.

Futhermore, we consider the verification method for our numerical studies for further research. We consider another experimental tests for the measuring acoustic signal during flights using microphone array mounted on multicopter.

5. ACKNOWLEDGEMENTS

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Table 1. Detail Specification of Multicopter Testbed

	Vendor	**Specification**	**Weight (g)**
Motor	T-Motor U7 V2.0	420 Kv	250
Propeller	T-Motor	Diameter 18 in Pitch 6.1 in	37
ESC	Hobby wing X-Rotor	Max 60 A	90
Battey	Tattu plus	10,000 mAh	1520
FC	Pixhawk	FMU V2	50
Takeoff Weight		10 Ah	5350

Table 2. Flight Test Conditions

Payload Weight (g)		0	400	600	1000	1250
Hovering		H1	O		H2	
Forward Flight	2					
	4	F1		O		O
	6					
	8	O		O		O
	10					O
H1/2 : Hovering Case 1/2 F1 : Forward Flight Case 1						

Table 3. Examples of Individual Motor RPMs

		M1	M2	M3	M4
Hovering Case 1		3689.1	3745.5	3733.9	3676.9
Hovering Case 2		3612.2	4016.8	4424.8	4198.8
FF Case 3	WP1-WP2	3486.7	3709.6	3778.8	4123.1
	WP2-WP1	3279.1	3690.4	3817.8	4147.9
	Average	3382.9	3700.0	3798.3	4135.5

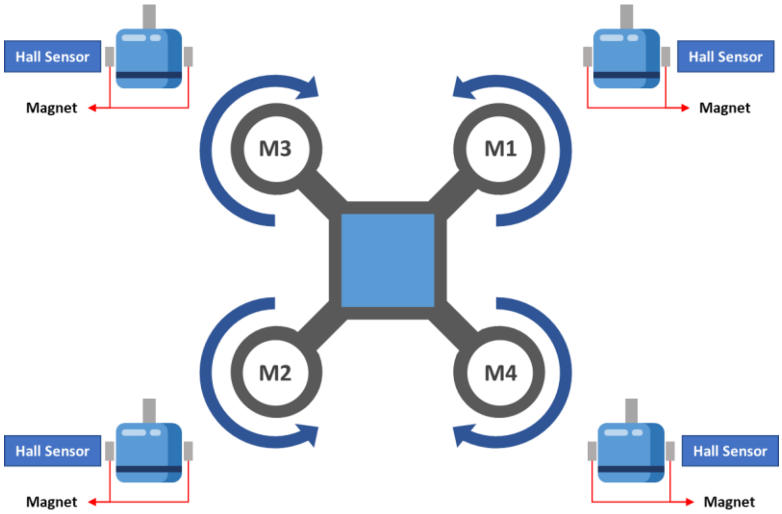

Figure 1. Schematic Diagram of RPM measurement on Individual motor

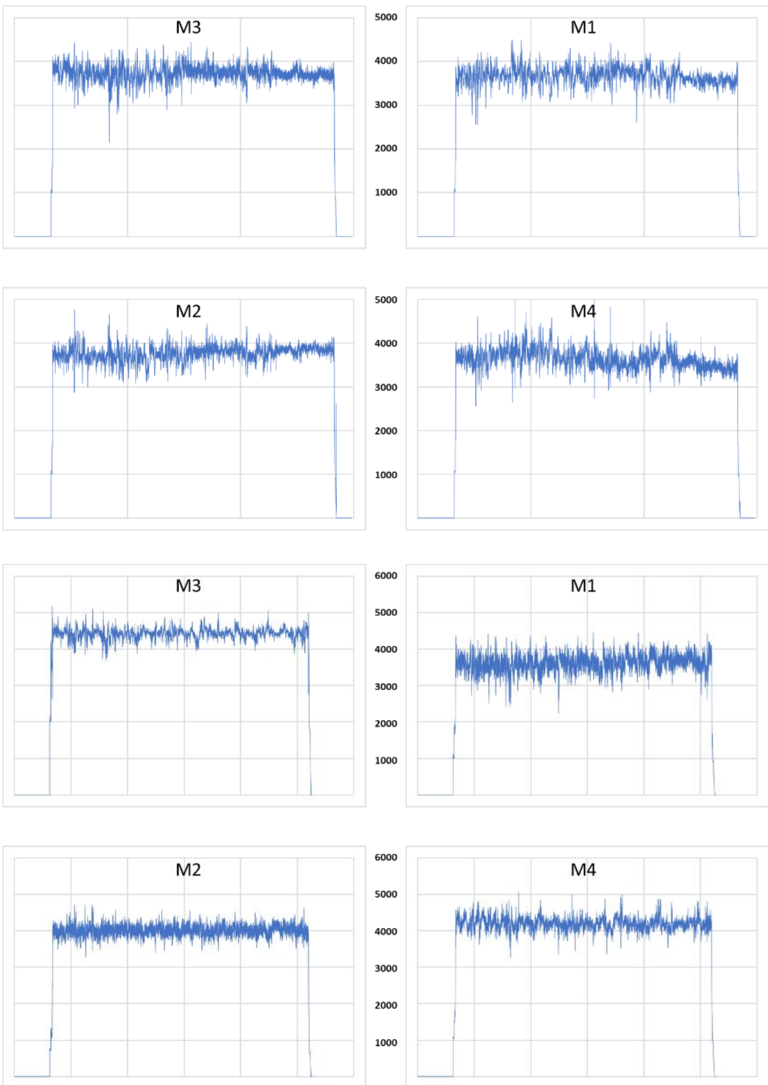

Figure 2. RPM Measurement Data for (upper) H1 Case, (lower) H2 Case

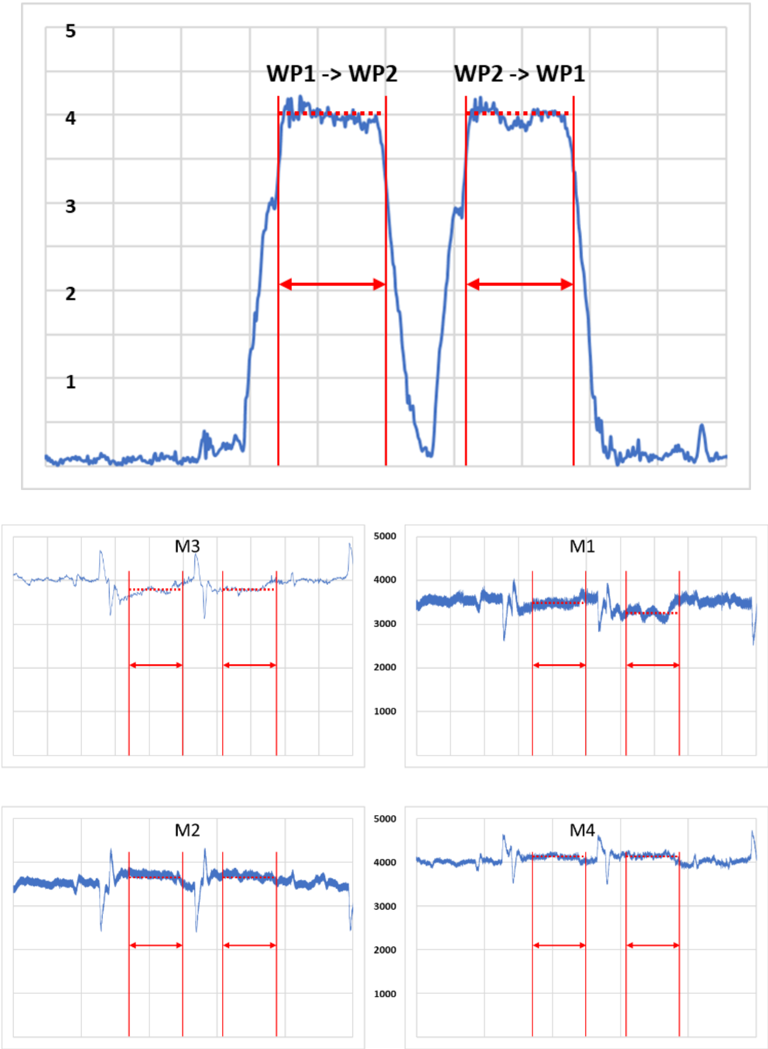

Figure 3. ***RPM Measurement Data for (upper) Speed-log written in FCC, (lower) F1 Case***

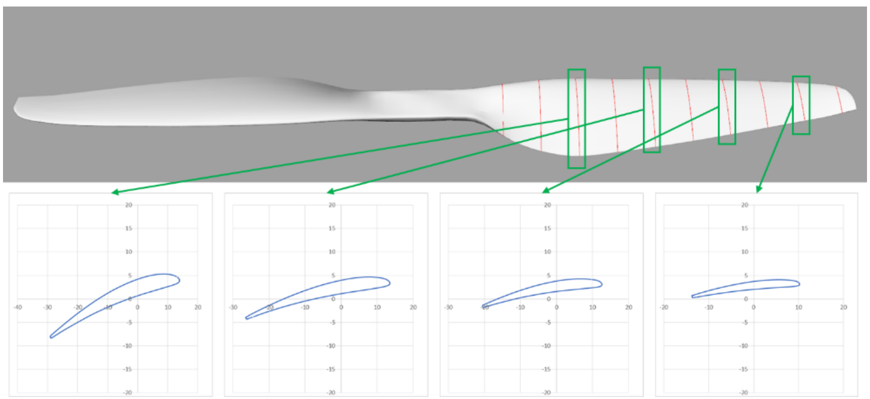

Figure 4. Propeller 3D Model and Sectional Airfoils

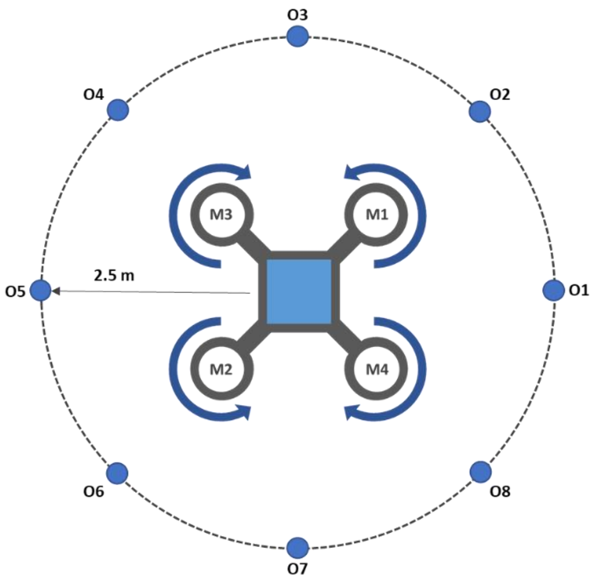

Figure 5. Observer Locations

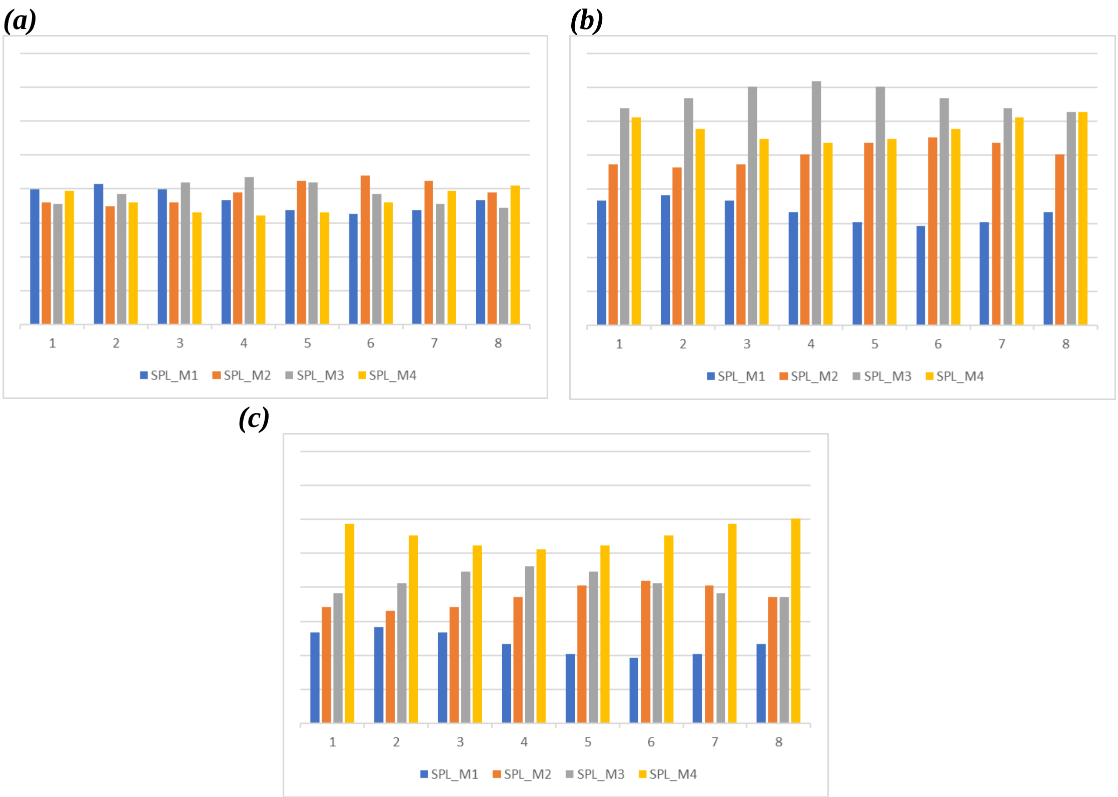

Figure 6. Comparison of Noise Emission Contribution of individual Propellers