Diffused Casing of Drone Propeller for Reduced Operational Noise and Optimized Energy Consumption

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ABSTRACT:

Drones have seen enormous applications in the world and continue to progress rapidly. But the main issues faced by drones are low flight time, high noise, and lower thrust-to-weight ratio. It makes the drone vulnerable in the long run, with lesser domains for application. The paper includes a passive method to decrease the noise of the propeller primarily. Using a cased diffuser can be helpful to counter the issues faced. It was found that the noise levels had dropped after using a diffuser casing. Along with that, there were other parameters like thrust and energy consumption, which have improved as a result.

Keywords: Drones, Noise reduction, Propulsion, Unmanned Aerial Vehicles

I. INTRODUCTION

At the advent of the 21st century, drones have become a crucial part. With diverse applications, they are significant areas of modern research. They are mainly used in situations where human interference is difficult to tackle issues like disaster monitoring, terrain analysis and in the defense sector [7]. Unfortunately, there are many problems faced namely high noise, low thrust-to-weight ratio and lower flight times due to high consumption. These problems prove to be a substantial factor that determines the flight path and the time for the same in the long run. This paper aims to solve one of the problems i.e. decrease in noise levels. An active method of countering the heavy noise problem is casing the propellers. But, a diffusing action at the outlet can give enhanced thrust since we do not want to affect the thrust in an adverse manner. As a result, lower noise levels with equivalent thrust can be achieved. This paper proposes a comparative analysis of open and cased diffuser propellers for two sizes of the propellers of the diameter 55 mm and 65 mm at different throttle values. The 55 mm and 65 mm propellers are easily available in the market making them the appropriate choice for the experiment.

II. LITERATURE REVIEW:

The use of casing has been prominent in marine technology for decades now [2]. They show the benefits of producing higher thrust with lower speeds and water as the working fluid. Air as the working fluid for propeller casing has shown similar results in many published articles. It is discussed in [1] that casing is necessary to increase the thrust and decrease power consumption. It also showed the variation of power consumption to thrust produced. It also mentioned that circular casings are approximately 4.5% more efficient than square casings [5]. So we have used circular diffuser casings for the experiments. The research report will comprise a study of the thrust and its noise level, as well as an experimental setup, trials, and data. Different designs and value differences are studied and the graphical representation shows the throttle and thrust increase percent value.

Another method of decreasing noise is the active method, by changing the structure of the propellers [3]. The paper involved the biomimetic structure of the propeller, inspired from owls. Owls have unique wing morphology like velvet surface, leading-edge serrations, and trailing-edge fringes due to which it is known for their silent flights. The study was inspired by the unique wing morphologies of owls, and after experimentation, attained 2.4 dB decrement in their noise levels.

III. HYPOTHESIS

The multi-rotor Unmanned Aerial Vehicles (UAV) are being extensively used and needed in numerous fields that have increased the importance of study of aerodynamics, such as secondary flows over the blades or noise reduction caused by propellers in the UAVs, and the optimization of the design on the propeller to increase efficiency of the UAVs. We have addressed noise reduction in this paper by reducing the induced noise of the propeller.

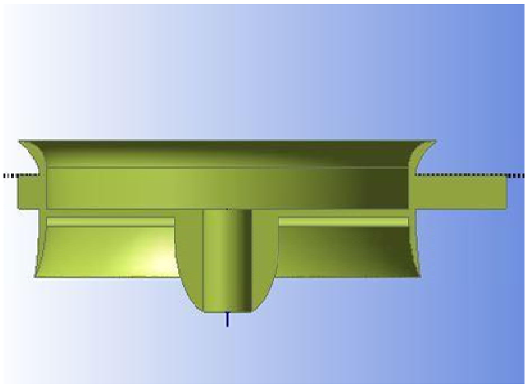
From the literature survey, the experiment to decrease the noise led us to diffused casing for the propeller. As the active method would be difficult to achieve, the passive method to reduce noise was adopted. It is known that by ducting, we disallow the high pressure air to enter low pressure space, which is the main reason for noise if allowed.

In this research, a novel approach is developed for designing a multi-rotor UAV diffuser that is low noise and efficient. The idea of producing diffusers over the propellers was devised to minimize the noise produced by the propeller. An acoustic analysis has been performed using ANSYS [9] and SOLIDWORKS [10] in order to generate the computer-aided design of the diffuser. A diffuser modified using a 3D Printer using PolyLactic Acid (PLA) material was finally completed.

IV. DIFFUSER CASING DESIGN

A propeller produces thrust using Newton's third law of motion and Bernoulli’s principle. The propeller creates a pressure gradient between the inlet and the outlet [6]. It gives rise to thrust, which is the resultant velocity gain experienced. A diffuser is a device that increases the pressure along the cross-section. According to Bernoulli’s principle, in the case of a diffuser, more thrust is experienced as more pressure gradient is observed. Moreover, having a nozzle intake decreases the inlet pressure, creating more pressure difference between the inlet and the outlet. The design made for the experiment includes all these factors along the length of the diffuser casing. It has a nozzle intake, diffuser outlet, and clearance casing for the propeller. The assumed design dimensions for the 55 mm and 65 mm propeller design are as follows:

1. Casing diameter = 55 mm/65 mm
2. Propeller clearance (δt) = 0.1% Diameter of the duct
3. Lip radius (Intake curve radius) =13% of the Diameter of the duct
4. Length of duct = 30% of the Diameter of the duct
5. Diffusing angle = 3.5° (Angle of the exit diffuser to the propeller radius)



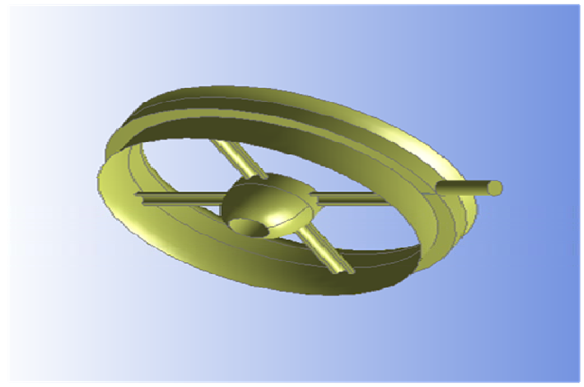


Fig.1 Diffuser casing cross section view

Fig.2 Orthogonal view of the diffuser casing

The diffuser casing increases the mass of the drone body at the expense of more thrust and lower noise. To have the optimum values for these variables, the weight of the diffuser casing should be as low as possible while having enough strength to withhold any crosswinds. The experiment includes 3D printed diffuser casings using PLA material. The mass of the diffuser casings for the 55 mm propeller and the 65 mm propeller are 5 grams and 8 grams increasing the weight of the drone body by 14.5% and 23.2% respectively. The resultant thrust produced should be higher than the total weight of the body and the diffuser casing to experience lift.

V. EXPERIMENTAL SETUP

The setup was made to find the noise emitted from the propeller. The diffuser ducts were printed for the 65 mm and the 55 mm experiments. The test bed was made by placing the diffuser on the weighing machine, along with counter weights. The weighing machine was set to grams. The controller was used to give the appropriate speed values to the propeller. The decibel meter was placed 10 cm from the propeller tip. As the transmitter gives the signal, the propeller starts rotating. The propeller then pushes the counter eights downwards, which is absorbed by the weighing machine plate, reflecting the thrust. The noise of the propeller is captured by the decibel meter.

Fig.3. 3D printed Diffuser duct (65 mm)

Fig.4 Experimental Setup

The experimental setup includes:

1. Weighing Machine
2. Transmitter
3. Decibel meter
4. Drone body
5. Diffuser casing with propeller
6. Counter weights (wooden solid boxes)

VI. EXPERIMENT TOOLS AND SPECIFICATIONS:

Component	Description
Controller	Naze 32 Brush
Frame	Qx95
Motor	8520 Coreless Motor, Max rpm - 40000, 3.7V
Transmitter	Fsi6
Receiver	Fs-Rx2a
Weighing Scale	DT830D Portable

Table.1 List of components and their specifications

VII. THEORETICAL CALCULATIONS

The theory of the propeller thrust is based on the Momentum theory [4]. The thrust force can be calculated by the mathematical terms equation [3]:

$T = 2\times\pi \times R^2 \times\rho \times \Delta\upsilon^2$ - (1)

Where,

T = Newton [N],

R = radius of the propeller (m)

ρ = density of air (kg/m3),

Δυ = the velocity of air accelerated by propeller (m/s).

But, $\Delta\upsilon = \frac{P}{T}$ - (2)

Hence equation (1) becomes $T = \sqrt[3]{(2 \times \pi \times R2 \times \rho \times P2)}$ - (3)

Where,

P = Power of motor transmitted to propeller, RPM = Revolutions per minute, P = Propeller constant × $RPM^{(power\ factor)}$ - (4)

Since the propeller and the motor used in the experiments are the same, hence the propeller constant and the rpm factor will be equal for the setup. But the Angular speed (RPM) will change, which will eventually change the thrust.

The RPM is calculated based on voltage supplied to the motor as shown in equation 5. As the voltage increases, the propeller speed increases.

$$RPM = Kv \times Voltage \quad (5)$$

Where, Kv = RPM per volt specification

Therefore, Kv = RPM/Voltage. At rated speed, Kv = 40000/3.7 = 10810.8 rpm/V

Since the maximum speed and voltage of the motor is 40000 RPM and 3.7 V respectively.

It can be concluded from this that the speed of the propeller is directly proportional to the voltage supplied to the motor. As the rpm decreases, even the voltage decreases. The current is the same for the motor, due to which, the energy consumption decreases.

VIII. OBSERVATIONS

The observations were taken for 4 throttle values i.e. 25%, 50%, 75% and 100%. The speed of the propeller changes as the throttle value increases, which in turn increases the thrust and the noise produced. The experiments are done on 65 mm and 55 mm propellers, along with their casing. The thrust is measured in grams and noise level in decibels.

Propeller Sizes and Thrust (in grams)				
Throttle	65 mm Open	65 mm Cased	55 mm Open	55 mm Cased
25%	12	26	10	16
50%	22	35	18	25
75%	25	37	22	29
100%	33	45	30	37

Table.2 Thrust at different throttle values

Propeller Sizes and Noise (in dB)				
Throttle	65 mm Open	65 mm Cased	55 mm Open	55 mm Cased
25%	90	88	85	82
50%	92	90	87	84
75%	93	92	90	88
100%	94	92	94	89

Table.3 Noise at different throttle values

IX. RESULTS

The observations above gave the results depending on the throttle values. The thrust and the noise are dependent on the speed of the propeller. This is visible in the readings showed above. The following results are shown below. In the graphs depicted, the Blue line depicts the Open Arrangement and the Red line is for the Cased System with diffuser.

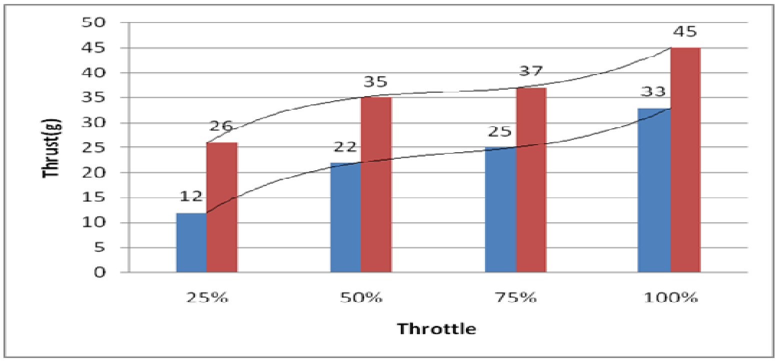


Fig.5 Thrust vs throttle for 65 mm propeller

Fig.5 is a graph of thrust (in grams) vs throttle for 65 mm Propellers. The blue line depicts the Open arrangement and the red line is for the cased system. It is observed that the thrust of the cased system is more than the open arrangement for all the throttle values. The Open propeller peaks at 33 g of thrust while the cased system touches 45 g of thrust.

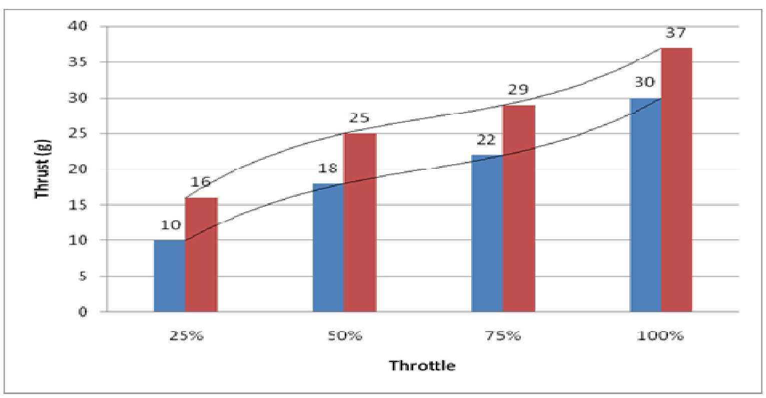


Fig.6 Thrust vs throttle for 55 mm propeller

Fig.6 is a graph of thrust (in grams) vs throttle for 55 mm Propellers. It is observed that the thrust of the cased system is more than the open arrangement for all the throttle values. The trendline is similar to that of the 65 mm propellers. The Open propeller peaks at 30 g of thrust while the cased system touches 37 g of thrust.

Fig.7 is a graph of noise (in decibels) vs throttle for 65 mm Propellers. It is observed that the noise of the cased system is less than the open arrangement for all the throttle values. The trend shows that there is an almost linear increase in noise for all the throttle values for the open system, but a polynomial curve for the cased system. The Open propeller peaks at 94 dB of noise while the cased system touches 92 dB.

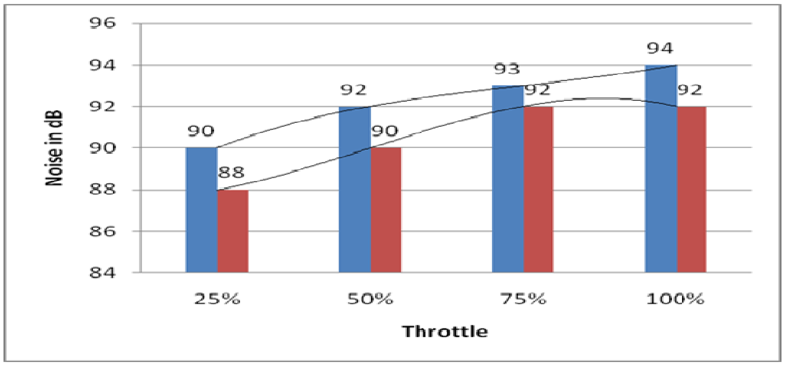


Fig.7 Noise vs throttle for 65 mm propeller.

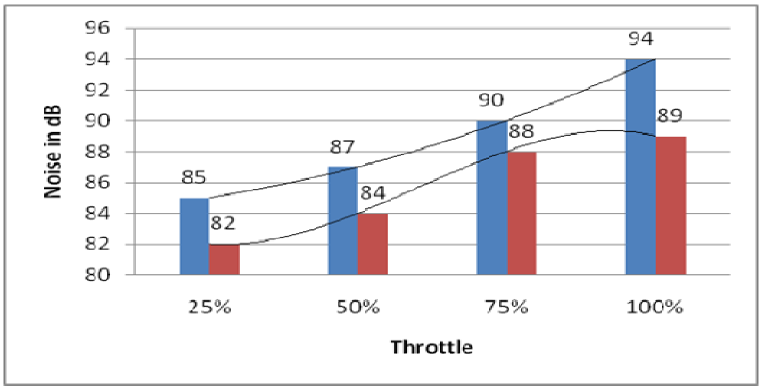


Fig.8 Noise vs throttle for 55 mm propeller

Fig.8 is a graph of noise (in decibels) vs throttle for 55 mm Propellers. It is observed that the noise of the cased system is less than the open arrangement for all the throttle values. The trend is similar to that of the 65 mm propeller. The Open propeller peaks at 94 dB of noise while the cased system touches 89 dB.

X. ANALYSIS and DISCUSSION

The results were further analyzed to find the values of dependent parameters. The data was used to determine any changes observed in the results and the magnitude as well. Following is the analysis of four parameters, namely Thrust increase percent, Noise decrease percent, RPM decrease percent and Energy decrease percent. All the values are of Cased system taken in comparison to the open propellers.

	Thrust increase %		**Noise decrease %**		**Energy decrease %**		**RPM decrease %**	
Throttle	**65 mm**	**55 mm**	**65 mm**	**55 mm**	**65 mm**	**55 mm**	**65 mm**	**55 mm**
25%	116.67	60	2.22	3.53	11.15	3.25	46	13
50%	59.09	38.89	2.17	3.45	17	7.5	34	15
75%	48	31.82	1.08	2.22	15	9	20	12
100%	36.36	23.33	2.13	5.32	16	9	16	9

Table 4. Parameters and the resultant changes observed

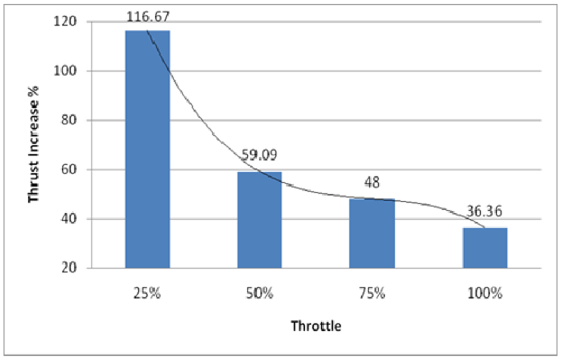


Fig. 9(A)

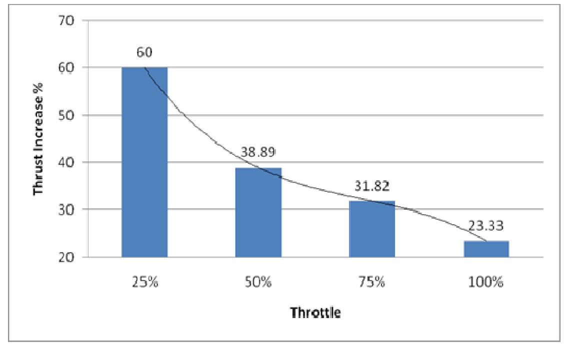


Fig. 9(B)

Fig.9 Thrust increase percent vs throttle for A) 65 mm cased Propeller B) 55 mm cased Propeller

Fig.9 is a graph of thrust increase in percent vs throttle for 65 mm and 55 mm Propellers. The graph shows that the thrust increment decreases as the throttle values are increased. The trendline is similar in both the cases, which shows that there is an almost exponential decrease in thrust increment for all the throttle values.

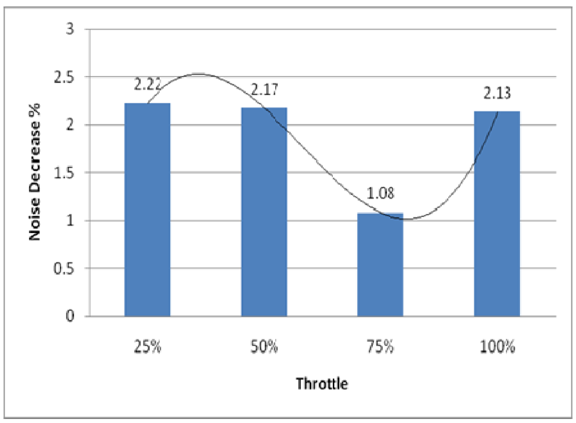


Fig. 10(A)

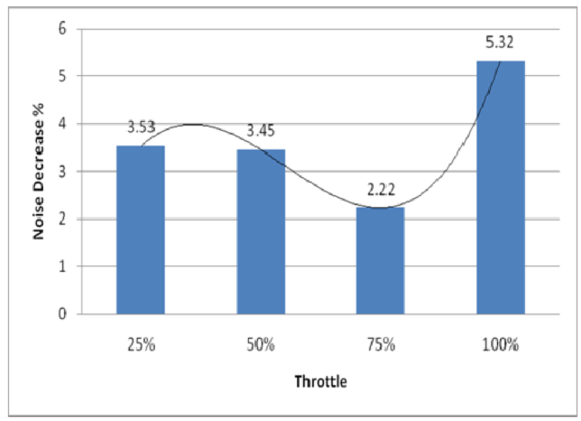


Fig. 10(B)

Fig.10 Noise decrease percent vs throttle for A) 65 mm cased propeller B) 55 mm cased propeller

Fig.10 is a graph of noise decrease in percent vs throttle for 65 mm and 55 mm Propellers. The graph shows that the noise decrement is cyclical as the throttle values are increased. The trendline shows that there is a sinusoidal curve produced in noise decrement for all the throttle values.

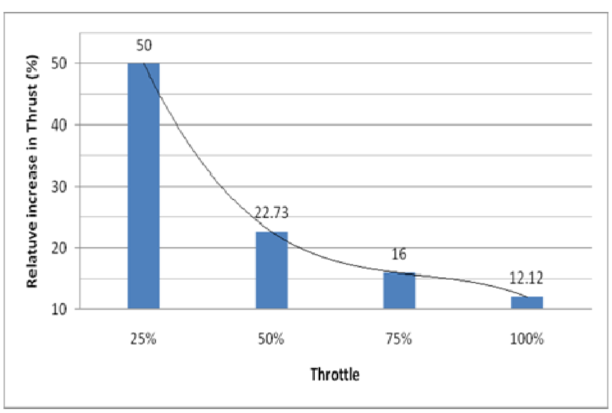


Fig. 11(A)

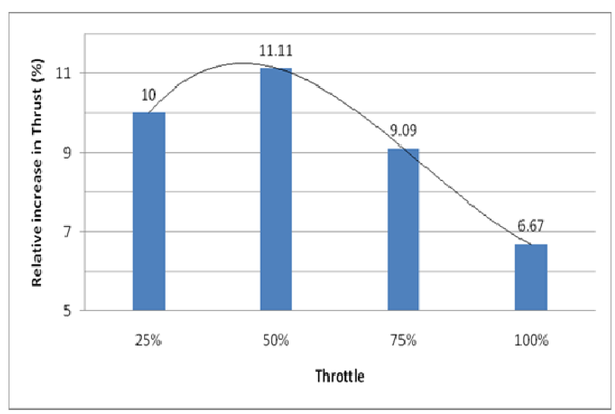


Fig. 11(B)

Fig.11 Relative increase in thrust vs Throttle for A) 65 mm cased propeller B) 55 mm cased propeller

Fig.11 is a graph of the relative increase in thrust against the throttle values for the 65 mm and 55 mm propeller. It is the thrust increment achieved due to casing, by deducting the mass of the diffuser casing.

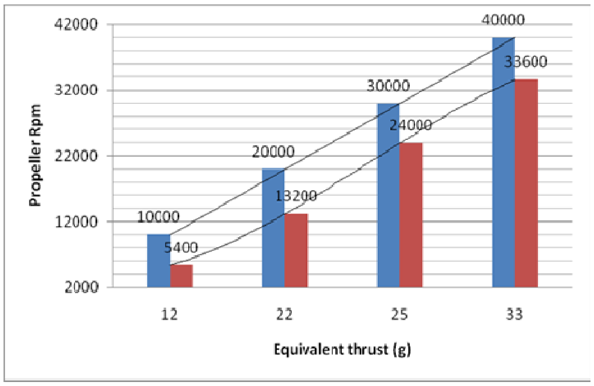


Fig. 12(A)

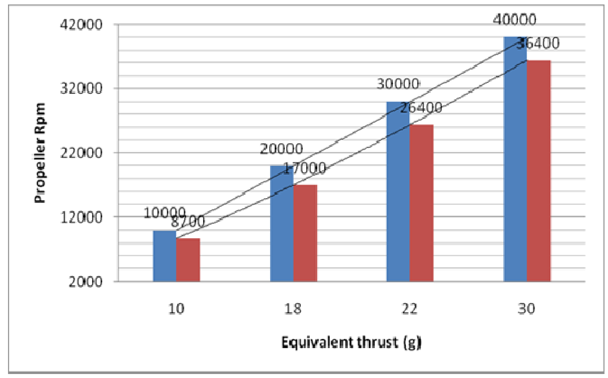


Fig. 12(B)

Fig.12 Propeller rpm for equivalent thrust for A) 65 mm propeller B) 55 mm propeller

Fig.12 is a comparative graph of the open propeller and the cased propeller for the 65 mm and 55 mm propeller. It shows the angular speed of the propeller needed to produce the equivalent thrust. As seen in the graph, to produce equivalent thrust, the cased propeller needs to run at lower speeds.

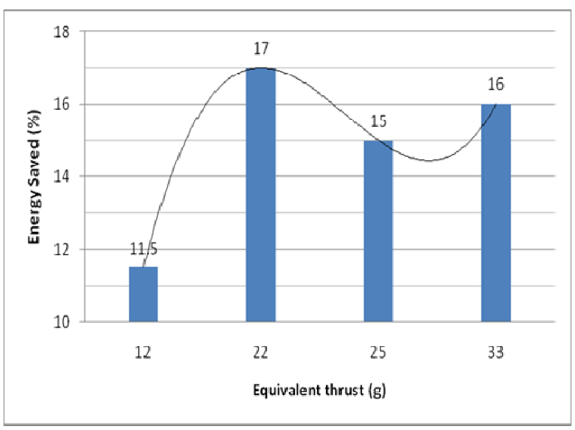


Fig. 13(A)

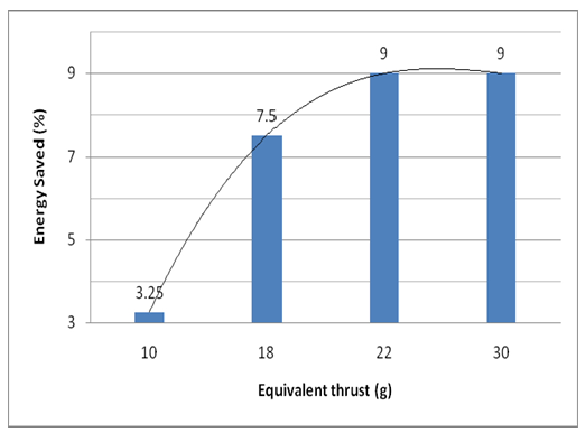


Fig. 13(B)

Fig.13 Theoretical Energy saved (%) vs Equivalent thrust (g) for A) 65 mm cased propeller B) 55 mm cased propeller

Fig.12 is a graph of the energy saved at the equivalent thrust for the 65 mm and 55 mm cased propeller. It shows the amount of energy saved to produce the equivalent thrust compared to the open propeller. It is taken by the relation that the number of revolutions have reduced (Fig. 11), which decreases the voltage needed, hence lesser wattage consumption. The trendline shows an erratic line for the 65 mm propeller, but consistently increasing for the 55 mm propeller.

XI. CONCLUSION

The above results show that the diffused casing produces lesser noise, compared to the open propeller. As expected, the decrease is not a lot, but sufficient. The combined noise of the four propellers of the quadcopter was observed to be 112 dB of sound pressure. It is very close to the maximum limit of the human ear. Not only did we experience a decrease in noise, but also an increase in thrust. An improvement was necessary as we did not want to compromise on the resultant thrust. But the increase in the resultant thrust was more than anticipated, giving a better thrust to weight ratio for the drone. It also provides the ground for lower energy consumption, as observed. The experiments depicted a decrease of up to 17% consumption by the motor, which would give more flight time. The noise can be decreased further by having a smaller clearance between the propeller blade and the diffuser casing. The use of chevrons has proven to mitigate the noise in Turbofan engines and could also play a pivotal role in drone propulsion in the future. Furthermore, lighter materials could make the diffuser casings have a higher thrust-to-weight ratio and propulsive efficiency. Further changes in design like smaller diffuser sections, different nozzle arrangements, and casing protrusions can provide better results and be the basis for future advancements in this technology.

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