Evrimata: Journal of Mechanical Engineering
Vol. 01, No. 04, December, 2024, p. 101 – 107 e-ISSN: 3047-6305

Single Propeller Design of Flying Electric Vehicles

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ABSTRAK

The growing demand for urban air mobility has spurred interest in Flying Electric Vehicles (FEVs), but challenges in propeller design, especially for single-propeller configurations, hinder progress. Traditional multi-propeller designs fail to address the energy inefficiency and aerodynamic instability critical to single-propeller systems. The lack of efficient, lightweight, and sustainable designs for FEVs exacerbates the problem, limiting their practicality for urban environments and beyond. This research aims to develop an optimized single-propeller design tailored for FEVs, focusing on improving static thrust performance while minimizing energy consumption and operational noise. By integrating advanced aerodynamic principles, innovative material science, and computational simulations, the study targets a robust and lightweight propeller prototype. It seeks to address inefficiencies in current designs and contribute to the broader development of sustainable aviation technologies. The methodology involves a blend of experimental and computational approaches, utilizing tools such as ANSYS and SolidWorks for aerodynamic simulations, and selecting composite materials like carbon fiber for enhanced durability and weight reduction. Key factors such as blade geometry, pitch, and airfoil characteristics were analyzed to achieve optimal thrust-to-weight ratios and energy efficiency. Static thrust tests and performance metrics validated the proposed designs, providing actionable insights into the effectiveness of single-propeller configurations.The results indicate that the optimized 32x10 propeller design significantly outperforms alternatives in thrust generation and energy efficiency, demonstrating the potential for practical application in FEVs. The study highlights the importance of integrating material innovation and precise aerodynamic calculations for advancing propeller technology.Future research should explore dynamic testing environments, further refinement of blade materials, and enhanced simulation accuracy. This would ensure scalability and adaptability for various FEV applications, paving the way for a new era in urban air mobility and sustainable transportation solutions

.***Keywords***: *propeller design, angle of attack, flying electric vehicle*

1. INTRODUCTION

The growing interest in flying electric vehicles (FEVs) as a viable solution for urban air mobility is met with significant challenges in design, performance, and efficiency. Among these challenges, propeller design plays a critical role, as it directly affects thrust generation, energy consumption, noise levels, and overall vehicle stability. The shift toward sustainable aviation necessitates efficient energy use, but existing propeller designs for electric vehicles often fail to maximize the energy-to-thrust ratio, leading to inefficiencies [1]. Additionally, the integration of a single-propeller system presents unique difficulties, including maintaining adequate lift and control while minimizing vibration and noise.

A key issue lies in optimizing the aerodynamic properties of the propeller. Traditional designs used in multi-propeller systems may not scale effectively for single-propeller configurations, leading to problems like asymmetric airflow and reduced efficiency [2]. Furthermore, electric power systems impose constraints on weight and power supply, necessitating lightweight yet durable materials and designs that can operate within the limitations of battery capacity.

Changing times have had a significant impact on many aspects, making things possible that were previously impossible. Transportation, for example, has changed tremendously as it allows human mobility over wider areas and more quickly. Although conventional machines have expanded the distribution of revolution in various sectors, their negative impact is uncontrolled. Therefore, humans try to restore previous conditions by modifying conventional machines. Technology, especially artificial intelligence, provides convenience and meets human needs in various fields. The conventional era must be replaced by modern technology that has a positive impact on human habits that are instantly responsive [3].

The use of unmanned aircraft (drones) is now widely used by civil society for various activities. The rapid development of unmanned aerial vehicle (UAV) functions and the easy availability of drones in the aerial photography industry have made it easy for many people to buy and operate drones freely. The use of drones has now been widely adopted by the public so that they can be used for various activities by the general public [4].

The world has now entered the Fourth Industrial Revolution (Era 4.0). This is marked by advances in the fields of robotics, e-commerce, computers with supercomputing capabilities, genetic engineering research, nanotechnology, automated vehicles, and other fields that are expected to increase productivity and make life easier for humans, the most prominent of which is the use of technology [5], [6]. unmanned aerial vehicles (drones). These changes occur more slowly than usual and will have a negative impact on changes in the areas of social, economic, industrial, political, judicial and community life. Drones bring new experiences in human evolution, triggering trends and changes in various fields. The convenience offered by drones makes activities more practical, such as large-scale fertilizer applications in agriculture. The increasingly common use of drone pilots and developments in their production are also occurring in the transportation sector [7]. The foundation of drones as unmanned aerial vehicles requires adjustments, especially in controlling the propellers for effective movement.

Various changes in shape, size and other factors affect the working of the propeller itself. The blade/propeller is an important component, because the blade is required to be able to move quickly and agilely, because it is required to maintain the balance of the drone while it is in the air [8], [9]. Drones are divided into 2 single propeller models for drones which have 1 blade/propeller on each engine. Contra rotating propeller is a system that has 2 blades on each engine [10].

Before conducting research, the author conducted several theoretical studies regarding single propeller simulation designs. And several literature studies were found to support the author in conducting this research. The author has determined several previous studies as a reference for conducting this research.

Therefore, researchers want to conduct research on planning electric flying vehicles. Which of course has been published. However, there are many similar products, some are even mass produced. Therefore, researchers want to focus more on single blade design planning for electric vehicles for static thrust force analysis. It is hoped that the results of this research can be the beginning of the development of flying electric vehicle blades in the future.

At the same speed, the thrust force is proportional to the size of the propeller, this shows that the more The bigger the propeller, the greater the thrust produced [11]. This is in accordance with the theoretical equation of static thrust force which states that the thrust force is proportional to the square of the pitch and diameter of the propeller. For adequate exploration and climb capabilities, the static thrust must be at least one third of the gross weight of the aircraft (at least 28.5 kgf). At 6500 rpm, propellers with sizes 30x12 and 32x10 produce thrust of 31 KgF and 34.8 KgF respectively. The 32x10 and 32x12 propellers produce thrust of 29.67 kgf and 32.93 kgf respectively at 6000 rpm. To optimize the available engine power and produce maximum thrust, the recommended propeller is a 32x10 propeller.

A similar study focused on airfoil selection for the LSU-03 aircraft. As part of this research, static propulsion tests of the LSU-03 aircraft were conducted at the Propulsion Laboratory to determine engine capabilities and select an appropriate propeller that would provide appropriate thrust for the aircraft and mission. Three types of 20 x 10 and 21 x 14 propellers were tested, and an S-beam sensor with a 100 kgF load cell was used to measure thrust. The results obtained from engine testing were validated by comparing them with calculation results using a propeller calculation application[11]

1. propellers

A propeller is a component used to move airplanes and ships which consists of a shaft driven by an engine. The propeller is a type of long blade which is a rotating airfoil on the driving rotor. A propeller is defined as a device with a hub and multiblade as a device that converts the rotational force of an aircraft engine into thrust.

A propeller is a propulsion system commonly used on airplanes and is driven by an engine or electric motor. The main components of a propeller are the hub and propeller. These two parts come together to form a propeller. The propeller or propeller has two parts, namely the front and the back [12]. The rear surface is the propeller surface seen from the axis side, while the front surface is called the front surface. The front edge of the leaf or blade is called the leading edge, while the reverse side is called the trailing edge [13].

2. lift style

In the propeller there can be results produced by the work of the propeller, namely the lift force or thrust force. Lifting force or what can also be called lift can be generated by a propeller, a helicopter propeller has an airfoil shape. The shape of this airfoil is curved at the top and almost straight at the bottom. Because of this unusual situation, air flows faster at the top of the surface than at the bottom. This speed difference creates a pressure difference between the top and bottom of the airfoil, which creates a force on the airfoil. The force on the airfoil can be formulated as equation 1[14].

$$L = \rho \; V \; 2 \; S \; CL \qquad (1)$$

Where, L = Lift (N), ρ = Density of air (kg/m^3), V = Velocity (m/s), S = Blade area (m^2) CL = Coefficient lift

The value of the description can be from the lift force obtained for the blade which is dependent and focused on the airfoil and angel of attack. So when the angle of attack increases along with that, the lift force will also increase, which will lead to a point where the drag force will dominate the lift force until the helicopter will have a stall effect. Then the lift is produced at a lower pressure on the top surface of the blade compared to the pressure on the bottom surface of the blade, thereby gaining pressure and causing the blade to lift upwards [15].

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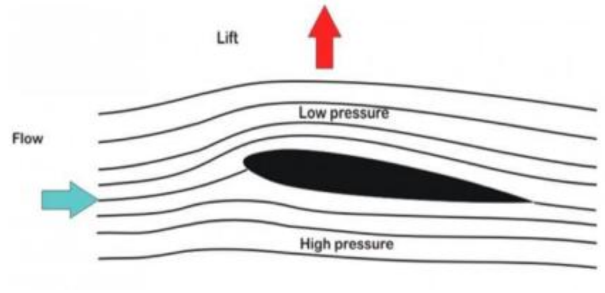

Fig 1 Airfoil style drawing[15]

Fig 1 illustrates the aerodynamic principles that occur in the wing or airfoil profile to produce lift. In this context, the air flow passing through the airfoil is divided into two, namely the flow above and below the airfoil surface. The air flow moving above the airfoil surface has a longer path than the air flow below it. This causes the air above to move faster, thereby lowering the pressure in accordance with Bernoulli's principle. In contrast, the air flow under the airfoil moves more slowly, which results in higher pressure. This pressure difference creates a lift force that pushes the airfoil upward.

Fig 1 shows the lift force is represented by the red arrow pointing upwards, while the direction of the initial air flow (freestream flow) is illustrated by the blue arrow pointing to the right. Lines indicating air flow (streamlines) provide an indication of the speed and pressure distribution around the airfoil. The top of the airfoil exhibits closer spacing between the flow lines, reflecting faster airflow and lower pressure. In contrast, the flow lines under the airfoil are looser, reflecting slower air flow and higher pressure.

This unequal distribution of pressure between the top and bottom of the airfoil is the essence of the lift mechanism. The design of the airfoil, including its curved shape and thickness, is designed specifically to optimize this pressure difference to produce a lift large enough to overcome gravity. In technological applications, this principle is used in the design of aircraft wings, propellers, and other aerodynamic elements to ensure maximum efficiency and performance.

3. airfoils

The lift force is a thrust force produced by a form of propeller, namely an air foil. An airfoil is a form of aerodynamic geometry that can produce a large lift force with the smallest possible resistance force when passing through a fluid. An airfoil itself is a surface that has a streamline that causes air to flow around its surface, producing pressure differences and sharp pressure, which then produces lift and drag. In other words, aerofoils aim to produce a lot of lifting power and reduce shear or drag power [15].

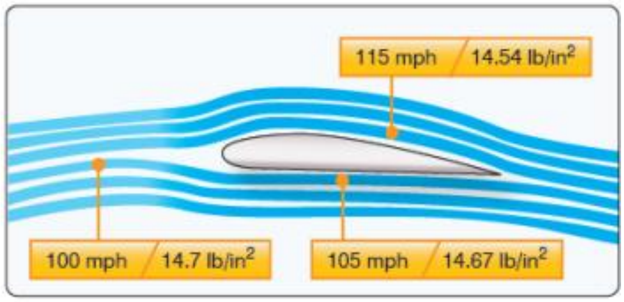

Fig. 2 airfoil drag force

In determining the propeller design, apart from determining the airfoil design. There are many factors that must be determined to support propeller reliability. Apart from that, one of the important factors that must be determined is the angle of attack of the propeller itself. The angle of attack is the angle that the bowstring of an aircraft's airfoil makes with the relative wing in contact with it. In normal terms, this is the angle the wing "strikes" the wind, or basically the angle of the wing relative to the direction the wind is hitting the plane [16].

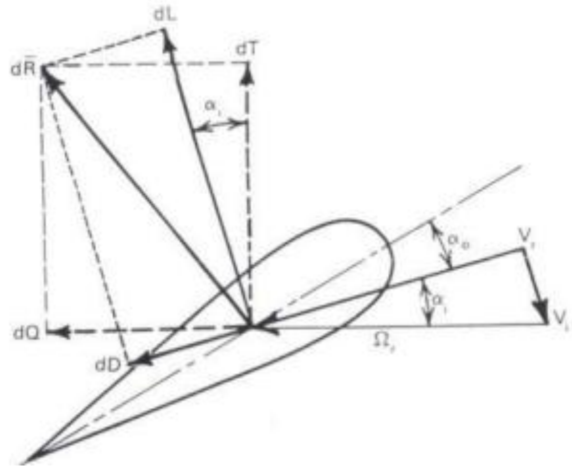

Fig 3 angle of attack formula

The angle of attack is the angle formed by the bowstring on an airfoil and in the direction of the air flow that should pass through it (relative wind). Generally it is marked α. For a symmetrical airfoil, the amount of lift produced will be zero if the angle of attack is zero, whereas even if the airfoil is not symmetrical, the angle of attack will remain zero but the resulting lift force will not be aerodynamic. The lift force will be zero if the airfoil is not symmetrical and forms a negative angle directly opposite the air flow. The angle of attack is obtained where the lifting force can produce a force with a magnitude of zero and can be called zero angle lift [17], [18].

4. propeller material

Various factors also need to be considered to design a propeller so that it can be used reliably. One factor that needs to be considered is the choice of material to calculate what materials can be reliably used in this propeller prototype. Various types of propellers can be used according to the specifications of the material. Some recommendations for propeller materials that the author used for this propeller prototype include:

a) Plastic

Plastic is a material that is often used in everyday life, because of its good level of efficiency and cheaper price, it is one of the material choices used in things that require strength and precision in shape, such as propellers.

b) Metal

Metal is a type of material that is often used for workpieces because of its strength, but if applied to propellers it is a little less appropriate, it is caused by weight [19], [20]. tall blades compared to plastic and composite propellers which increase the empty weight of the aircraft and reduce the motor's response to commanded speed changes

c) Composite

Composite propellers eliminate shape constraints caused by plastic or metal, resulting in thinner, more efficient propellers and enabling greater aerodynamic performance. Composite materials are currently starting to experience a transition from composite materials reinforced with synthetic fibers to reinforced materials [21], [22]. One of the composite materials which is also used for quadcopter propellers is carbon fiber. Carbon itself is a fairly strong material with its fibers being arranged together, making the resulting strength quite strong. Because carbon fiber has a fairly thin thickness, the resulting weight efficiency is quite good with very strong strength. These various advantages make carbon an option for Quadcopter propellers.

5. Blade Element Subdivision

In determining whether the propeller is reliable or not to be used in the passenger drone project this time, it is necessary to determine it using linear calculations. In order to be able to consider whether the propeller complies with the initial specifications that have been determined or not. Therefore, several theories were added to support determining the shape of this propeller prototype.

The propeller blade can be decomposed into segments. Assuming each segment only has axial and angular velocity components, and ignoring the induced flow from other segments, flow analysis can be carried out separately. With the propeller set at a certain geometric pitch angle (θ), the local velocity vector will shape the flow angle of attack at each segment.

Lift and drag forces, both normal and parallel to the propeller disk, can be calculated. This allows us to determine the contribution of each segment to the thrust and torque of the propeller, with the flow angle of attack on each segment as the basis for the calculation. The angular difference between the directions of the thrust and lift forces is defined as equation (2).

$$\varphi=\theta-\alpha \quad (2)$$

Thus, the thrust force and element torque of this blade element can be written as equation (3).

$$\Delta T=\Delta L\cos(\varphi)-\Delta D\sin(\varphi) \quad (3)$$

$$\Delta Q/r=\Delta D\cos(\varphi)+\Delta L\sin(\varphi) \quad (4)$$

per blade, where ρ is the air density, c is the blade chord so that the area that produces lift on the blade element is c,dr. If the number of propeller blades is B then,

$$\Delta T=\frac{1}{2}\rho V_1^2 c(C_L\cos(\varphi)-C_D\sin(\varphi))B.dr \quad (5)$$

$$\Delta Q=\frac{1}{2}\rho V_1^2 c(C_D\cos(\varphi)+C_L\sin(\varphi))B.r.dr \quad (6)$$

6 Simple Blade Element Theory

Simple blade element theory is the most widely used propeller theory. In this theory, the blade is divided into several different elements. The lift and torque are calculated by each of these elements which are then added together to find the total thrust and torque. The total thrust for a propeller having a number of blades B is given by equation (2). Likewise, the torque is given by equation (3), where B is the number of blades, ρ is the air density, V is the speed, b is the chord, r is the blade radius, and CL is the lifting coefficient. The efficiency is given by equation (4). Shows a velocity i diagram with reaction at an angle.

$$F_L=\int_0^T\frac{1}{2}\rho V^2 bdrBC_L\frac{\cos(\gamma+\emptyset)}{\cos(\gamma)Sin^2(\emptyset)} \quad (7)$$

$$Q=\int_0^T\frac{1}{2}\rho V^2 bdrBC_L\frac{\sin(\gamma+\emptyset)}{\sin^2(\emptyset)cos(\gamma)} \quad (8)$$

$$\eta=\frac{F_tV}{2\pi nQ} \quad (9)$$

7 Airfoil Calculations

Airfoil calculation is a mathematical and physical process used to analyze and predict the aerodynamic properties of airfoils, which are propeller-shaped profiles used in drones, helicopters and various other types of air vehicles. The goal of airfoil calculations is to understand how the airfoil interacts with the air flow, including generating lift and drag.

This calculation process involves mathematical approaches and numerical simulations to solve equations that describe the air flow around the airfoil. Several factors considered in airfoil calculations include the geometric shape of the airfoil, the angle of attack relative to the air flow, the air flow velocity, and the fluid properties of the air.

Table 1. Airfoil calculation

AI	AJ	AK
cl	cd	AoA
-0.3859	0.07827	-5
-0.3815	0.04817	-4
-0.2822	0.03773	-3
-0.1835	0.03284	-2
-0.0804	0.0296	-1
-0.0071	0.02894	0
0.1946	0.03437	1
0.3454	0.038	2
0.4891	0.04082	3
0.621	0.04303	4
0.7051	0.04737	5
0.773	0.05345	6
0.8179	0.06172	7
0.8604	0.07029	8
0.9429	0.0731	9
1.0136	0.07554	10
0.9443	0.10095	11
0.8836	0.12803	12

Table 1 shows the results of airfoil calculations can provide important information to aircraft designers to improve aerodynamic performance, efficiency and aircraft stability. It is also used in the development and testing of new prototypes before mass production.

Lift and Drag Coefficient: Cl measures the efficiency with which an airfoil produces lift, making it an important parameter in airfoil analysis and design. On the other hand, Cd quantifies the amount of drag generated by the airfoil during its movement in the air. Lower Cd values indicate

reduced drag and higher aerodynamic efficiency. These values are determined through airfoil calculations. To obtain the Cl and Cd values for various parts of the propeller blade, polynomial fitting was carried out using the results obtained from the airfoil lift and drag coefficients. [23], [24], [25].
The purpose of this research is to develop an optimized single-propeller design for flying electric vehicles (FEVs), focusing on enhancing static thrust performance. The study aims to address critical challenges in propeller design, such as improving energy-to-thrust efficiency, reducing noise and vibration, and ensuring stability in single-propeller configurations. By integrating advanced aerodynamic principles, material science, and simulation techniques, this research seeks to create a propeller prototype that maximizes thrust generation while maintaining lightweight and durable characteristics. This endeavor not only contributes to the advancement of FEV technology for urban air mobility but also provides a foundational framework for future studies and developments in sustainable aviation.

2. RESEARCH SIGNIFICANCE

The significance of this research lies in its contribution to advancing the design and development of single-propeller systems for flying electric vehicles (FEVs). As the demand for urban air mobility solutions increases, the need for efficient, sustainable, and reliable propulsion systems becomes critical. This study provides a foundation for understanding and improving the aerodynamic performance, structural reliability, and energy efficiency of single-propeller designs specifically tailored for FEVs. By focusing on static thrust force analysis and utilizing advanced simulation tools such as ANSYS and SolidWorks, this research aims to address key challenges in achieving optimal thrust-to-weight ratios, minimizing energy consumption, and ensuring stability and maneuverability. Furthermore, the findings from this study are expected to contribute to the broader field of electric aviation by offering insights into material selection, blade geometry, and aerodynamic principles, paving the way for future innovations in passenger drone technology. This research not only fills a gap in the literature on single-propeller systems but also serves as a stepping stone for the development of efficient, scalable, and environmentally friendly flying vehicles that align with the goals of sustainable transportation in the Fourth Industrial Revolution..

3. RESEARCH METHODS

The experimental research is research that attempts to find the influence of certain variables on other variables under strictly controlled conditions, there are 4 types of experimental research, namely pre-experimental, true experimental, factorial and quasi-experimental. The experimental research based on its variations consists of pure experimental research, quasi experimental research, weak experimental research and single subject experimental research.

3.1 Materials

Several tools and materials are selected based on the equipment that will be used to support the manufacture of the propeller. The materials used include.
1. Carbon
One of the composite materials that is often used to strengthen objects, it is also light and corrosion resistant, besides having flexible design capabilities.
2. Resins
Resin is a chemical material that is often used as a matrix in fiber composites such as carbon fiber and glass fiber
3. Fiber
It is one of the composite materials used for initial coating, apart from its flexible design capabilities, this material is also often used for coating objects.
4. Cardboard paper
Used to help shape the initial design so that the design can be as desired

4. RESULTS AND DISCUSSION

Propeller design research is a complex and multidisciplinary process involving various scientific fields such as aerodynamics, materials, mechanics, and engineering. The main objective of this research is to develop a propeller that is efficient and effective in producing the thrust required for certain applications, such as airplanes, drones, ships or flying electric vehicles.
The thrust produced by a single propeller on a drone is the force that pushes the drone up or forward, depending on the orientation of the propeller. The thrust produced by a single propeller on a drone is the result of the interaction between the propeller blades and the surrounding air, which produces a pressure difference and creates a force that propels the drone. The rotation speed, size, and design of the propeller all affect how much thrust is generated, and by controlling this thrust, the drone can fly and maneuver as desired.
The thrust coefficient is a parameter used to describe the efficiency of a propeller in producing thrust. This is a dimensionless number that helps engineers and designers understand propeller performance under various operating conditions. The thrust coefficient (C_T) is the ratio between the thrust produced by the propeller and the product of the fluid density, the propeller disk area, and the fluid flow velocity (or relative wind speed) squared.

Table 2. The results of simulations

M	2000			4000			6000
ı	gaya thrust		run	gaya thrust		run	gaya thrust
1	1,1858		1	4,7479		1	1,0683
2	0,8009		2	3,2042		2	7,2095
3	0,5637		3	2,3299		3	5,2423
4	0,3970		4	1,6603		4	3,8048
5	0,2898		5	1,1981		5	2,7018
6	0,2194		6	0,8634		6	1,9013
7	0,1678		7	0,6051		7	1,3038
8	0,1257		8	0,4218		8	0,8558
9	0,0890		9	0,2780		9	0,5232
10	0,0587		10	0,1732		10	0,3236
	3,8979			15,4820			24,9344
	0,38979	0,88764		1,5482	2,09532		2,49344

Table 2 shows the results of this data, which are the results of simulations that have been carried out to test the thrust force produced by the propeller. At 2000 RPM, 10 experiments were carried out and 10 data results were obtained. The average lift force produced is 0.38979 N at 2000 RPM. Furthermore, at 4000 RPM, 10 trials were also carried out and an average result of 1.5482 N was obtained. At 6000 RPM, 10 more trials were carried out and an average thrust force was obtained of 2.49344 N. This data was then presented in form tables and graphs to assess whether the thrust force produced is in accordance with the requirements borne by the propeller. The graph above the table shows the relationship between RPM and thrust, with the horizontal axis representing RPM and the vertical axis representing lift (thrust force). This graph shows the trend that the thrust force increases with increasing RPM, which is shown by a relatively linear increase in the curve from 2000 to 6000 rpm.

5. CONCLUSION

The conclusion of this research shows that the design and simulation of a single propeller on a passenger drone provides significant results in several key aspects. The proposed propeller design successfully meets the criteria for aerodynamic efficiency and flight stability, taking into account the passenger load and desired flight duration. Simulations show that the use of a single propeller is able to produce sufficient lifting power to lift passenger loads while still maintaining efficient energy consumption.

Apart from that, the simulation results also indicate that setting the correct propeller pitch and diameter is very important to achieve optimal performance. This study also highlights the importance of selecting light and strong materials for propellers to improve safety and efficiency. However, there are several limitations in this research, such as limitations in the simulation model which cannot fully replicate real flight conditions.

Thus, this research concludes that single propellers can be a viable alternative for passenger drones, as long as they are supported by a mature design and the right technology. Further research is needed to test this design in real conditions and explore potential improvements in terms of maneuverability and safety.

6. ACKNOWLEDGMENTS

The author would like to thank the support from Malang State Polytechnic in completing this research..

7. AUTHOR CONTRIBUTIONS

Conception and design: Abbi ewton syahyogi
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Writing Publications: Abbi ewton syahyogi, Sugeng Hadi Susilo
Final publication approval: Abbi ewton syahyogi, Sugeng Hadi Susilo
Resources, technical and material support: Abbi ewton syahyogi, Sugeng Hadi Susilo
Supervisor: Abbi ewton syahyogi, Sugeng Hadi Susilo

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