International Journal of Electrical, Energy and Power System Engineering (IJEEPSE)
e-ISSN: 2654-4644
Vol. 6, No. 1, pp. 133-137, February 2023
http://www.ijeepse.id

Effect of Vortex Generators on Airfoil NACA 63_2-415 to Aerodynamic Characteristics Using CFD

Gusty Widyawati
Department of Mechanical Engineering
Universitas Trisakti
Jakarta, Indonesia
gusty061001904011@std.trisakti.ac.id

Rosyida Permatasari*
Department of Mechanical Engineering
Universitas Trisakti
Jakarta, Indonesia
rosyida@trisakti.ac.id

**Corresponding author: Rosyida Permatasari, rosyida@trisakti.ac.id*

Abstract*— To determine the aircraft's flight performance, the airfoil type must be considered when designing the wing. A vortex can form when the airfoil travels through a fluid stream with a difference in velocity and pressure around it. Airfoil modification is carried out to delay the occurrence of flow separation by adding a vortex generator. This paper discusses how adding the vortex generator helps slow the stall's onset and how the vortex generator affects the fluid flow and aerodynamic forces acting on the NACA 632-415. The vortex generator profile is positioned at an x/c = 20% of the chord line's direction from the leading edge. The variation used is an airfoil's angle of attack (α). Some parameters to be evaluated include the coefficient lift force (CL), the coefficient drag force (CD), and the gliding ratio (CL/CD). The research was conducted by the CFD method based on the angle of attack that produces the coefficient lift and drag forces. The addition of the vortex generator can delay the flow separation, increase the lift force coefficient by about 24.9%, the drag force coefficient by about 2.7%, and the gliding ratio by 9.1%.

***Keywords*— angle of attack, CFD, coefficient lift, gliding ratio, vortex generator.**

I. Introduction

Extreme weather often encourages humans to take several preventive and countermeasures, one of which is the operation of weather modification technology. One of the methods used in this activity is seeding using NaCl sown in the clouds, so it requires an airplane. With special weather modification needs, the aircraft also requires good aerodynamic performance. The aerodynamic aspect will affect the flying performance of an aircraft. Modifying the aircraft components with aerodynamic aspect values is necessary to improve the aerodynamic aspects. The wing design determines the main aircraft component that produces the lift and the drag forces [1]. Everything that happens in the aircraft wing area, between the wing tip and the wing root, will impact the magnitude of the lift force and the resulting drag force [2].

The ideal wing design should theoretically have an infinitely long span. However, this prevents wings from having an infinite span length. As a result, the aircraft's wings have limited dimensions that are proportional to the length of the fuselage. The limited span of a wing will impact the aerodynamic performance of a wing capable of producing flow separation due to the difference between the two boundary layers in the area of the wing root and tip. The vortex flow on the aircraft wing through the airfoil can be caused by differences in the flows. The airflow coils make the drag force stronger and the lift force weaker. The aircraft's performance will suffer when the drag force coefficient is high. Therefore, the airfoil's design must be modified to achieve the desired lift force coefficient and minimize the drag force coefficient [1].

To determine flight performance, paying attention to other aspects such as taper ratio, aspect ratio, and sweep angle is necessary. The aspect ratio is determined by comparing the length of the aircraft wing span to the average aerodynamic chord or the ratio of the square of the length of the wing span to the chord. So that the stall angle decreases proportionally to the wing's AR, the maximum lift coefficient will increase if the AR value increases [2].

The ratio between the front of the chord (root chord) and the chord's tip (tip chord) is the taper ratio. The effect of the taper ratio on how the wing weight is distributed is that if the value of the taper ratio is lower, the wing weight will be lighter because the center of gravity will move toward the fuselage, which produces lateral stability. The taper ratio determines the aircraft's wing planform. The taper ratio decreases with decreasing wing thickness [3]. Another aspect to determine the flight performance is sweep angle. The sweep angle is the angle that forms between the lateral angle and the chord line that runs along the aircraft's wing span [4].

The Fig. *1* explains the boundary layer on the airfoil surface. At the leading edge of airfoils, a laminar boundary layer is formed. The flow of velocity is relatively low near the leading edge. The fluid can dampen flow disturbances brought on by vibrations and irregularities at the surface boundary, preserving laminarity at the boundary layer. Shear forces and viscosity cause more flow disturbance the further away from the leading edge [5]. A laminar boundary layer will form near the leading edge of the fluid flow that is moving and encircling the airfoil surface. The fluid can still accept any disturbances the flow may encounter due to irregularities and vibrations at the boundary surface. As a result, the boundary layer

Received: Feb 17, 2023 | Revised: Feb 26, 2023 | Accepted: Feb 28, 2023

continues to be laminar. Due to the fluid's viscosity and increased shear forces, as it moves away from the leading edge, the flow will enter a transition state before becoming a turbulent boundary layer [5].

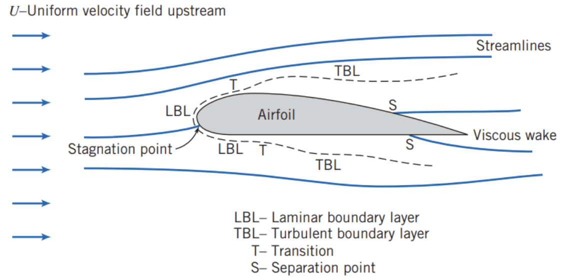

Fig. 1 Boundary layer state [6]

The fluid flow holding the airfoil in place forms a stagnation region in addition to the laminar boundary layer and the turbulent boundary layer. When the fluid meets the airfoil at the leading edge, it is called stagnation point. The fluid velocity is zero, and the pressure extremely high in the stagnation area. An area of separation is characterized by a negative pressure gradient in which the fluid's pressure rises while its velocity decreases. Backflow occurs on the surface of the airfoil due to this this phenomenon [5].

A wing made from the shape of the airfoil. When its span is extended to resemble a finite wing, an airfoil ceases to be two-dimensional even though it has lift and drag forces. A vortex is the rolling airflow at the wing tip [7]. Because if the difference in pressure between the surfaces of the upper and lower of the airfoil, the vortex can form. The stream will roll down the back of the wing as plane moves forward. When rolling flow induces a section behind the wing, which ini turn induces changes in local flow around the wing, the AOA induced by a downward vector [3].

As they travel through the air, airplane wings typically move in the same direction as the airflow. The term angle of attack (AOA) refers to the angle formed by the airflow's direction towards the chord line [7]. The value of AOA produce by the aircraft wing has an impact on the lift force value. The variation in the AOA will have an impact on the lift value. The AOA will affect the lifting force differently. As the AOA is raised and the center of pressure moves forward, the lift force will rise [8].

A wake area is a space in a fluid flow created by flow separation [5]. The pressure and flow velocity fluctuate along the airfoil's surface. The airfoil's leading edge typically results in the formation of a laminar boundary layer. When the boundary layer expands, a transition from a turbulent boundary layer to a laminar boundary layer will occur. The fact difference between turbulent flow and laminar flow is that the random oscillatory motion of turbulent flow is significantly more effective that molecular motion in transporting the mass and momentum of the fluid [9]. The aerodynamic properties are significantly affected by the significant distraction between turbulent flow and laminar flow. Both of the have distinct profiles, with turbulent flow appearing wider or fuller than laminar flow. The velocity of a turbulent profile decreases to zero at the surface and stays fairly close to the free-flow velocity from the outer edge to a point near the surface. In contrast, from the outer edge to the surface point, the velocity gradually falls to zero in a laminar profile [1].

Layers with greater turbulence at the boundary always generate more full momentum, resulting in stronger momentum close to the friction plane's surface. The more full a flow is, the more turbulent it is. Compared to laminar flow, the turbulent flow has a velocity profile with a thicker disturbance thickness but a much larger momentum near the wall [3]. The wall provides ample momentum, allowing the more turbulent flow to overcome the pressure and frictional resistance despite the identical free flow velocity. Near wall flow is better able to withstand adverse pressure by increasing flow turbulences, which reduce likelihood of secondary flow. It will make an effort to increase the turbulence flow by adding a turbulent generator to the supporting area [10]. A type of turbulent generator known as a vortex generator (VG) is shaped like fins. the installation of VG is needed to generate lift on the aircraft. As a result, the lift force for each VG produces a change in flow on the aircraft wing [11].

The most important factor in determining the value of flying efficiently is the aircraft's aerodynamic performance. The adverse pressure gradient causes boundary layer separation, which impacts flight performance [1]. Installing a turbulent generator on the airfoil's upper surface is one measure to lessen the impact. A vortex generator is one type of turbulent generator [5]. The vortex generator or VG can be used to increase the lift on the airfoil in one of several ways that have already been implemented [12][13][14].

A method of numerical analysis known as computational fluid dynamics (CFD) makes use of a computer to obtain information (predictions) about the patterns of fluid flow under specific time and space conditions. In addition to being unique to the flow of air, this is used for pressure distribution analysis. The CFD method makes it easier, more effective, and more efficient to predict fluid flow in various systems (designs) than when the design was directly applied to the experimental method. In addition, the CFD-based fluid flow prediction results are more comprehensive than those from the experimental approach, which has problems with measuring instruments' accuracy, availability, cost, and precision [15].

II. Methodology

A modeling-simulation approach is utilized in this study. The amount of C_L, C_D, and the gliding ratio will be determined using the simulation-generated data. The approach generally consists of two stages: airfoil model simulation through flow simulation and geometry modeling through the input of airfoil coordinates. The simulation uses a range of angle of attack from 0° to 25° with interval 5°. The details of coordinates of NACA 63_2-415 shows in Fig. 2.

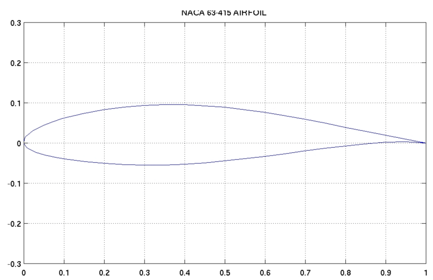

Fig. 2 NACA 63_2-415 coordinates

This study using a wing of Piper Cheyenne that uses the NACA 63_2-415 airfoil as it shapes. And also, vortex generator geometry data that mentioned in TABLE I.

Received: Feb 17, 2023 | Revised: Feb 26, 2023 | Accepted: Feb 28, 2023

TABLE I AIRFOIL AND VORTEX GENERATOR PARAMETERS

Piper Cheyenne II		*Vortex Generator*	
Parameter	Dimension	Parameter	Dimension
Wing Span	200 mm	Length	40 mm
Chord Line	260 mm	Spacing	110 mm
Freestream	25,72 m/s	Thickness	1 mm
Range angle of attack	-0º, 5º, 10º, 15º , 20º, and 25º	Height	0.75 mm
Type	NACA 63(2)-415	x/c	0.2 mm
Position	*Entrance Region*	Type	*Gothic co-rotating*
		Total	26 pcs

The flow diagram is required to describe the study's process because the design steps can be performed, as shown in Fig. *3*.

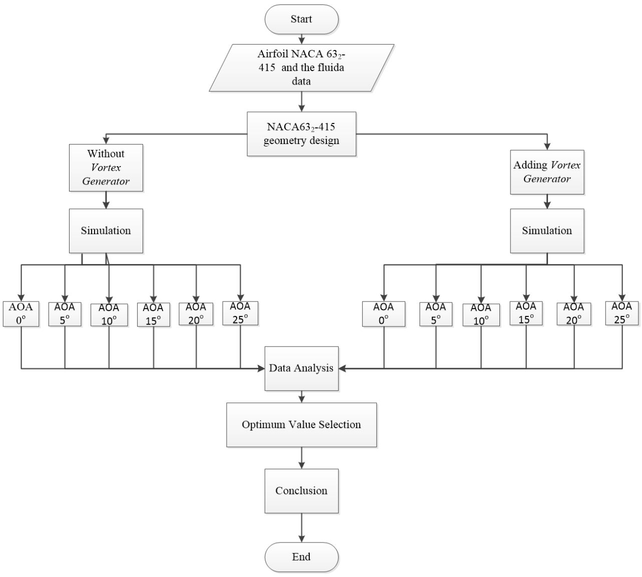

Fig. 3 Flowchart of methodology

The tools used in this project are computer and software ANSYS 17.1. the material used is the airfoil on the Piper Cheyenne II PA-31T (NACA 63_2-415). The research was conducted from a variety of angle of attack. The first step is pre-processing by creating a geometry model of Piper Cheyenne II PA-31T wings and a vortex generator model, determining the boundary conditions on the airfoil. Second step is to analyze the data from the simulation. The final step is to analyze the simulation's data and draw conclusions from the result [16]. Descriptive statistics are used to analyze the data by performing a data analysis of the collected. The lift and drag force graphs created by the ANSYS FLUENT simulation software.

III. Result And Discussion

In two experiments, the simulation on the airfoil without the addition of VG and the simulation on the airfoil with the addition of VG. The outcomes of the airflow profile analysis simulation on the airfoil using the ANSYS FLUENT software were demonstrated. This analysis was carried out to determine the characteristics of the fluid passing through the airfoil without adding a VG and the characteristics of the fluid passing through the airfoil with addition of a VG. The aerodynamic characteristics considered on this analysis are both airfoils' lift and drag coefficient. Each experiment was carried out with variations in the angle of attack starting from 0º until 25º with interval 5º. The speed of aircraft is 50knots. The flow phenomena that occur around NACA 63_2-415 airfoil can be qualitatively explained through visualization which based on numerical data simulation. From the Fig. *4*, the changes in AOA variations can be seen to have shifted the stagnation point downward. Therefore, the stream's leading edge moves faster toward the upper surface of airfoil. Visually the airfoil with the addition of VG shows reduction the wake area on the airfoil without adding VG at an angle of 10º. Meanwhile, at an 5º, the airfoil without VG has a larger wake area. At each increasing in AOA, the airflow velocity contour visible through the air experiences a great flow velocity on the upper surface than on the lower surface. The air velocity of the airfoil with adding VG shows more stable flow according to the increasing AOA.

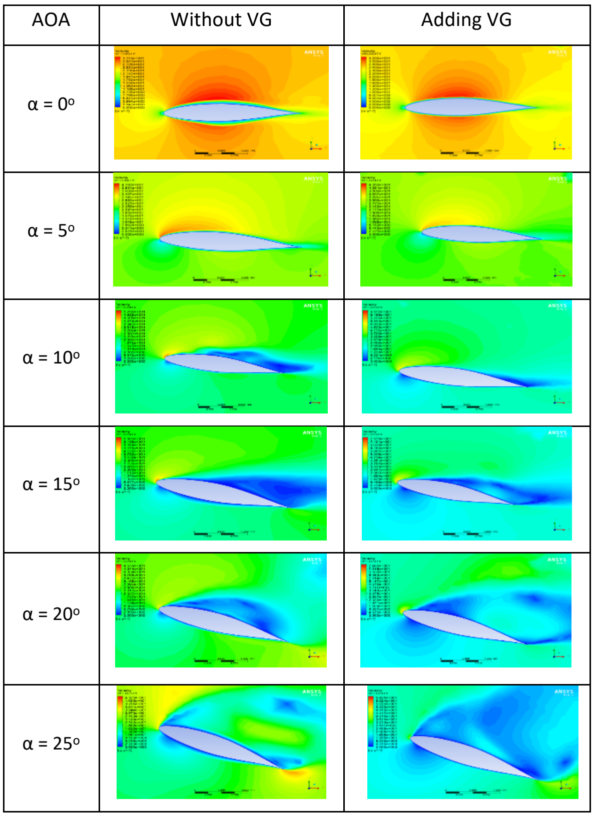

Fig. 4 Visualization of airflow velocity on NACA 63_2-415 airfoil contours

Where the green area on the non-VG airfoil has a negative pressure coefficient (-2.44x10^2 Pa until -1.03x10 Pa), while the yellow and orange areas have a positive pressure coefficient (2.865x10 Pa until 3.797x10^2 Pa). From Fig. 5 at an AOA of 15º, the comparison of pressure distribution that occurs on the airfoil without the addition of a VG with the distribution of pressure that occurs on the airfoil with the addition of VG. In this simulation, the lower surface of airfoil with adding a VG have a higher value than the lower surface of airfoil without adding a VG that shows from the contour.

The decrease in the pressure value at the upper surface of the airfoil makes airflow from the lower surface of airfoil to upper surface of airfoil. If there is a very high pressure difference, it will cause accelaration in the flow near the endwall. The accelerated fluid will flow to the upper surface, opposing the secondary flow's backward flow and reducing the secondary flow with high momentum.

Received: Feb 17, 2023 | Revised: Feb 26, 2023 | Accepted: Feb 28, 2023

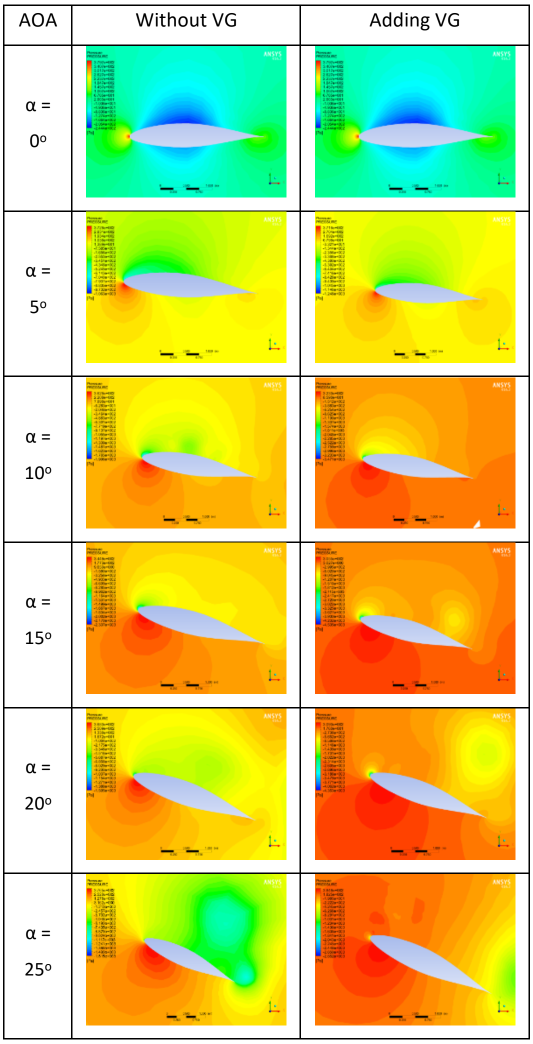

Fig. 5 Visualization of pressure distribution on NACA 632-415 airfoil contours

Table II shows that the value of the lift coefficient can be increased with the addition of VG. The largest increase in the value of the lift coefficient occurred in the airfoil with adding of VG at AOA 20°, which was 44.32%. While the smallest increase was at AOA 5° which was 8.83%. Adding VG to the airfoil with an AOA of 20° provides the advantage of increasing the lift coefficient (C_L) value. This is possible happen due to the velocity vector values that generate the flow momentum in streamline direction that disrupts the flow and speeds up separation.

TABLE II COMPARISON OF AERODYNAMIC VALUES ON AIRFOIL WITHOUT VG AND AIRFOIL WITH ADDING VG

AOA	Without VG			Adding VG			Δ		
(α)	C_L	C_D	C_L/C_D	C_L	C_D	C_L/C_D	C_L	C_D	C_L/C_D
0^0	0.156	0.014	11.064	0.133	0.012	11.359	14.81%	17.02%	2.67%
5^0	0.889	0.072	12.338	0.81	0.063	12.774	8.83%	11.94%	3.54%
10^0	1.14	0.214	5.3148	1.309	0.204	6.4061	14.91%	4.66%	20.53%
15^0	1.133	0.446	2.5423	1.594	0.508	3.1376	40.64%	13.96%	23.42%
20^0	1.092	0.605	1.8057	1.576	0.883	1.7839	44.32%	46.08%	1.21%
25^0	0.533	1.014	0.5255	0.755	0.631	1.1971	41.64%	37.82%	12.8%

Fig. 6 Lift coefficient on NACA 632-415 shows a graphic of coefficient of lift force value that have a bigger value for aircraft with using VG. The highest value for coefficient of lift force is 1.576 at AOA 20° after that the airfoil loses lift force that causing a stall and the coefficient of lift becomes 0.775. At AOA 15° and 20°, the coefficient of lift has the same range value is about $C_L = 1.5$.

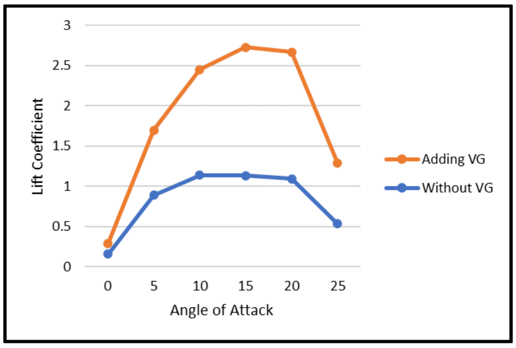

Fig. 6 Lift coefficient on NACA 63_2-415

Fig. 7 shown a coefficient of drag also increases in accordance with the increase in the coefficient of lift. At AOA 10°, the addition of VG resulted in the lowest drag coefficient (4.66%), while at AOA 20°, the highest drag coefficient value was recorded (46.08%). If there is a reduction in the drag coefficient and an increase in flow momentum, the installation of VG gives advantageous. When VG is attached to the airfoil, the drag coefficient value also rises according with each increase in AOA. Flow deflection, which makes it harder to optimize VG usage, is probably due to the rising in the drag coefficient's value. The value of the C_L/C_D ratio has increased after the addition of vortex generator by 23.42% at AOA of 15°. Due to an increase in AOA and an adverse pressure gradient, this occurs. The flow resistance to frictional forces increases.

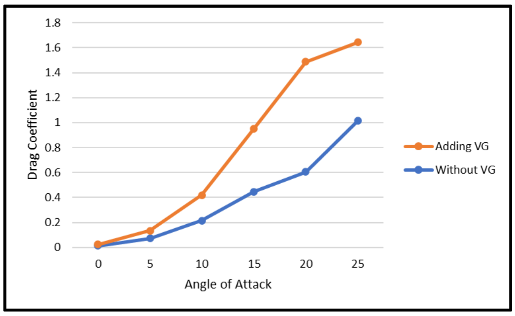

Fig. 7 Drag coefficient on NACA 63_2-415

The graph indicates that the airfoil with VG has a lift coefficient that is greater than that of the airfoil without VG. In addition, the graph of the drag coefficient with VG has a value that decreases at an AOA of 20°, indicating that the drag coefficient can decrease in comparison to the graph of the drag coefficient on airfoil without VG, which typically continues to rise.

IV. Conclusion

This study's findings can be summarized that without the addition of VG, the characteristic of aerodynamic for airfoil have an increasing C_L value and a C_D value that also increases with each increase in AOA. In addition, the characteristic of aerodynamic for airfoil that were modified with VG, resulting in an increase of 24.9% in the C_L value and 2.7% in the C_D value. The value of the aircraft's lift force can increase with an increase in C_L. With VG at an AOA 20°, the airfoil saw the greatest increase in C_L. The value of C_L/C_D coefficient ratio rises by 9.1% when VG is added to an aircraft, resulting in improved flight performance over aircraft without VG. For this type of airfoil, at a 15° of AOA, the airfoil with adding VG value is at its best.

Received: Feb 17, 2023 | Revised: Feb 26, 2023 | Accepted: Feb 28, 2023

ACKNOWLEDGMENT

A special acknowledgment is addressed to the Studio CAE FTI and Laboratorium Teknik Mesin FTI Universitas Trisakti for their outstanding contribution to this study as well as the generosity and expertise of one and all have improved this study innumerable ways.

REFERENCES

[1] J. D. Anderson, *Fundamentals of Aerodynamics (6th edition)*, vol. 1984, no. 3. McGraw-Hill Education, 2011.
[2] S. M. Berkowitz, "Theory of wing sections," *J. Franklin Inst.*, vol. 249, no. 3, p. 254, 1950.
[3] A. M. Kuethe and C. Y. Chow, *Foundations of aerodynamics: bases of aerodynamic design*, 3rd editio. 1976.
[4] M. H. Sadraey, *AIRCRAFT DESIGN Aerospace Series List Design and Analysis of Composite Structures: With applications to aerospace Structures*. 2013.
[5] E. L. Houghton and N. B. Carruthers, *Aerodynamics for engineering students.* The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK: Butterworth-Heinemann, 1982.
[6] Sukoco, "Upaya Peningkatan Gaya Angkat Pada Model Airfoil Dengan Menggunakan Vortex Generator," *J. Aircr.*, vol. 5, no. 2, 2015.
[7] Ajoy Kumar Kundu, *Aircraft Design*, vol. 4, no. 1. United States of America by Cambridge University Press, New York: ISBN-13 978-0-511-67785-4 eBook (NetLibrary), 2557.
[8] A. Ghurri, "Aliran Fluida Internal dan Eksternal," p. 76, 2015.
[9] Er. R. K. Rajput, *A Textbook of Fluid Mechanics and Hydraulic Machines*. 2011.
[10] V. T. Gopinathan and M. Ganesh, "Passive Flow Control over Naca0012 Aerofoil using Vortex Generators," *Int. J. Eng. Res.*, vol. V4, no. 09, 2015.
[11] K. A. Raykowski, "Optimization of a Vortex Generator Configuration for a 1 / 4-Scale Piper Cherokee Wing," 1999.
[12] Aleks Udris, "Vortex Generators: Preventing Stalls At High And Low Speeds," 2015. https://www.boldmethod.com/learn-to-fly/aerodynamics/vortex-generators, accessed Apr. 27, 2021.
[13] S. S. Hariyadi, W. Aries Widodo, K. Person, and S. Hariyadi Jl Arief Rahman Hakim, "Studi Numerik Efek Variasi Posisi Vortex Generator Terhadap Boundary Layer Pada Airfoil Naca 43018," *Semin. Teknol. dan Rekayasa*, no. SENTRA, 2015.
[14] H. Tebbiche and M. S. Boutoudj, "Optimized vortex generators in the flow separation control around a NACA 0015 profile," *Proc. Int. Conf. Struct. Dyn. , EURODYN*, vol. 2014-Janua, no. July, pp. 3219–3226, 2014.
[15] R. Permatasari and M. Bambang Susetyarto, "Effect of Evaporator Outflow Rate on Air Distribution in the Computer Laboratory using CFD," *Int. J. Electr. Energy Power Syst. Eng.*, vol. 3, no. 3, pp. 89–93, 2020.
[16] R. Design, "CHEMKIN Tutorials Manual CHEMKIN ® Software," *Design*, no. December, pp. 1–274, 2011.

BIOGRAPHIES OF AUTHORS

GUSTY WIDYAWATI was born in Jakarta on August 14, 1997. Furthermore, her educational background was graduating from D3 Mechanical Engineering, Polytechnic State of Bandung 2018 and graduated from Mechanical Engineering, Trisakti University in 2023. The authors has work experience at National Research and Innovation Agency, Republic of Indonesia.

ROSYIDA PERMATASARI born in Jakarta on September 27, 1966. Furthermore, her educational background was graduating from S1 Mathematics,ITB in 1991, graduated from Mechanical Engineering, University of Indonesia in 1999 and graduated from Mechanical Engineering Universiti Teknologi Malaysia (UTM) in 2013. The author is a lecturer at Department of Mechanical Engineering, Universitas Trisakti. Her main area of expertise is energy conversion.

Received: Feb 17, 2023 | Revised: Feb 26, 2023 | Accepted: Feb 28, 2023