



Experimental Study of Fluid Flow Characteristics in Wing Airfoil Naca 43018 with Parabolic Vortex Generator Using Oil Flow Visualization

D. Zhela Trie^(✉), Setyo Hariyadi, and I. S. Rifdian

Politeknik Penerbangan Surabaya Jl. Jemur Andayani I/73, Surabaya 60236,
Jawa Timur, Indonesia

zheilatriedhayanti@gmail.com

Abstract. Aircraft is the science of aerodynamics that is associated with fluid flow, which is related to performance in today's aviation. One of them is technological advances in the world of aviation, namely various developments and modifications of airfoils that are carried out to delay flow separation, one of which is with a vortex generator. The flow separation event in the frictional flow on the surface of the wing (boundary Layer) can cause a stall. Therefore, by delaying the separation, the drag will be small and will get an increase in the lift force. The research study is the characteristic of fluid flow that crosses a parabolic vortex generator with the oil flow visualization method. This study aims to visually observe the fluid flow characteristics on the upper surface crossing the NACA 43018 airfoil with varying positions of the vortex generator and angle of attack (AoA). The vortex generator profile is positioned $x/c = 20\%$ from the leading edge. By using variations of Reynolds Number (Re) and angle of attack (α) on the airfoil. The freestream speed used is 20 m/s, at angles of attack (α) = 0° , 4° , 10° , 12° , 15° , and 17° . It can be proven that this research with the addition of a parabolic vortex generator increases the aerodynamic performance of the airfoil, where the aircraft from AoA 0° to 12° proves that the increasing speed of the transition to the laminar boundary layer is concluded to be a turbulent boundary layer. Based on visual experiments using a parabolic vortex generator, it shows that there is a delay in flow separation on the upper surface of NACA 43018 at an angle of attack of $\alpha = 12^\circ$ to 15° .

Keywords: Aircraft · NACA 43018 · Aerodynamics · Wing · Drag

1 Introduction

In this era, the development of technology is increasing, without us realizing the development of the aviation world is already far more advanced than when the first flight in the world. In addition, air transportation is very common, tens or even hundreds of passengers can fly in one departure, but the question is why such a large plane can fly. For example, the civilian aircraft 777 with a net weight of 134.8 tons reaches 167.8 tons

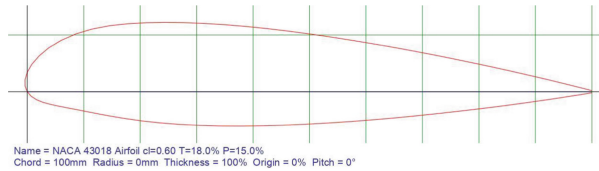


Fig. 1. Airfoil NACA 43018

with additional Fuel, Cabin, Messenger, etc. The main part of the aircraft, the wing of the aircraft is one of the main parts of the aircraft in the form of an airfoil connected to the wing attachments point fuselage (aircraft body) and also the components that fly the aircraft. Various wing designs, sizes, and shapes are installed in the fuselage's top, middle, or bottom position (airframe). These designs are called high-wing, mid-wing, and low-wing.

In an aircraft manufacturing process, an analysis of the aerodynamic performance of the aircraft is first carried out so that the aircraft has a high level of safety, especially in areas where empirical/analytical methods cannot be reached. From several aerodynamic analysis methods, the wind tunnel testing method for aircraft models is still very reliable and reliable as a method that is quite effective. Each aircraft design uses the lift force by its provisions, to achieve this, a high AoA (angle of attack) (α) is required, as can be seen in Fig. 1. When soars high, it creates a high drag force. Therefore, a vortex generator is applied to the surface. In previous years, vortex generators have been studied by many experts including Kharge et al. [1], Velte et al. [2], Hussein et al.[3] etc.

The workings of the aerodynamics test are by using a wind tunnel. This wind tunnel can work by sucking air from outside in the room in the form of a venturi tube, inside the venturi there is a NACA 43018 test instrument, then the addition of a parabolic vortex generator. This research will only use airfoil type 43018 as shown in the figure as a study of aerodynamics test objects, with wind tunnel data recorder testing on a PC. From previous research, Setyo Hariyadi[4] analyzed position VG on the wing airfoil NACA 23018. This test occurred to improve lift performance and NACA 43018 with the addition of PVG (Parabolic Vortex Generator) compared to without a vortex generator. With the application of the Parabolic vortex generator, it can delay the occurrence of separation points. Research using oil flow visualization has previously been carried out by many experts including Pierce et al.[5], Karthikeyan et al. [6], Tianshu [7], Esfahani et al. [8], Jiu [9], Mario [10], Binhua et al. [11], Terzis et al. [12] etc.

NACA stands for "Airfoil National Advisory Committee for Aeronautics", this airfoil is popularly used in aerodynamic studies. In one example of a simple aerodynamic wing shape, it can function to provide a certain lift/lift to a wing shape which is also called an airfoil and with this mathematical solution, it is very helpful to make it possible to estimate the amount of lift that data can generate from an airfoil.

In this series, the first number calculates the design value of the lift coefficient, the first number is multiplied by 3/2, then multiplied by tenths. The next two digits indicate the location of the maximum relative camber over the string. The two digits indicate the percentage thickness of the string.

2 Methods

The experiment is an activity of research and experimentation to produce a new product or prove a hypothesis/conjecture. The design of the wing airfoil with special digits NACA 43018, where the dimensions and configuration of the NACA 43018 airfoil refer to research that has been carried out by Hariyadi[13] and examines changes in the angle of attack, lift and drag that resists the influence of air circulation through the top of the airfoil. It can be observed the cross-sectional profile of the NACA 43018 airfoil is an illustration of the test object in this swallow.

Analysis with many dimensions is very necessary to find out whether the parameters are very influential in a study. Here are presented the flow parameters to be measured are:

- 1. The density of the fluid, (kg/
- 2. Fluid velocity, U (m/s)
- 3. Boundary layer thickness, (m)
- 4. Airfoil thickness, x (m)
- 5. Distance between flat plate wall and Airfoil, G (m)
- 6. Airfoil Chord Length, c(m)
- 7. Vortex Generator Height, i (m)
- 8. Vortex Generator Length,l (m)
- 9. Distance from leading edge to Vortex Generator, t(m).

The placement of the vortex generator parameters used in this study is shown in the Table 1 and Fig. 2.

Table 1. Design experimental

PARAMETER	EXPERIMENT
Shape	Parabolic
H	0.0086.c
l/h	3
AoA	0°, 4°, 10°, 12°, 15°, and 17°
x/c	20%
C	200 mm
D	0,182.c
Position	Straight
V	10m/s, 20 m/s

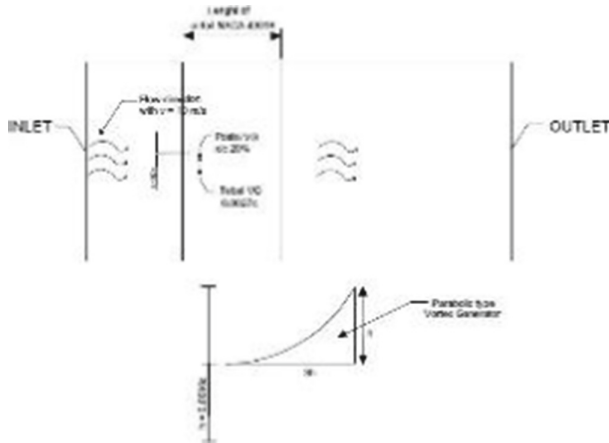


Fig. 2. Position of VG in experimental research



Fig. 3. Wind Tunnel for experimental research

The equipment that will be used in this research is, Wind Tunnel. The flow is considered incompressible at the inlet and wind tunnel. Incompressible flow is a flow in which the volume does not change due to changes in pressure, for example, air (Fig. 3).

Test section shape: Rectangular cross-section:

1. Length: 1800 mm
2. Height: 660 mm
3. Width: 660 mm.

The working process of the wind tunnel is free stream velocity will enter through the back of the wind tunnel and then smoke is given so that the air mixed with smoke will pass through the NACA 43018 airfoil.

3 Result

The experiment that analyzes the dynamics characteristics of fluid flow on the upper surface is one of the results of the simulation with the WT-60 subsonic wind tunnel. And from these results, It can be seen that calculated Separation points (X_s), reunifying (X_r), and transition points (X_t) in the form of how much PVG (parabolic vortex generator) is added in various variations of the angle of attack AoA (angle of attack) and viscosity (Fig. 4).

As a reference in analyzing the separation point, two wind tunnel simulations were carried out on the plain airfoil and the airfoil with the addition of a parabolic vortex generator. The experimental results on the NACA 43018 airfoil test with the addition of variations of the parabolic vortex generator AoA (angle of attack) and Viscosity to this study, obtained the value of X_s / separation point, X_r or reattachment point, and X_t or transition points as follows (Table 2).

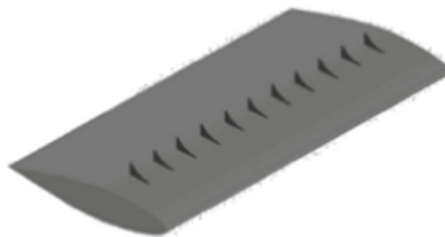


Fig. 4. Parabolic Vortex Generator

Table 2. Research results on airfoil without vortex generator

Re	α	X_s	X_r	X_t
1×10^5	0°	0.51	0.99	0.40
	4°	0.50	0.91	0.38
	10°	0.41	0.80	0.31
	12°	0.39	0.70	0.19
	15°	0.11	–	0.06
	17°	0.07	–	–
2×10^5	0°	0.54	0.97	0.40
	4°	0.48	0.89	0.38
	10°	0.44	0.83	0.22
	12°	0.40	0.72	0.19
	15°	0.31	-	0.18
	17°	0,09	–	–

It is known in the table above that airfoil research without using VG. As seen in the Table 3 the airfoil research use the Vortex Generator.

Installation of PVG (parabolic vortex generator) on the surface of the wing can accelerate the transition from changing the laminar boundary layer to the turbulent boundary layer, so that with the installation of PVG (parabolic vortex generator, airflow through the upper surface wing has a relatively higher speed than non-vortex generators/without installation) vortex generator. The application of PVG is more relevant to the angle of attack $\alpha = 10^\circ$ and 12° .

This experimental setup displays the results of visualization of airflow with the oil flow visualization method or spraying smoke using a mixture of oil and fuel, turbulence contours, and fluid flow dynamics which are useful for knowing how it works and the effect of adding a parabolic vortex generator to the NACA 43018 airfoil. The oil flow visualization method is applied to the upper surface airfoil NACA 43018 with variations in the angle of attack $\alpha = 0^\circ, 4^\circ, 10^\circ, 12^\circ, 15^\circ$, and 17° at $Re = 1 \times 10^5$ and $Re = 2 \times 10^5$ (Fig. 5).

Table 3. Research results on an airfoil with a parabolic vortex generator

Re	α	X_s	X_r	X_t
1×10^5	0°	0.58	0.98	0.21
	4°	0.55	0.90	0.20
	10°	0.47	0.85	0.22
	12°	0.44	0.75	0.21
	15°	0.34	–	0.19
	17°	0,05	–	–
2×10^5	0°	0.55	0.99	0.21
	4°	0.57	0.92	0.23
	10°	0.49	0.86	0.20
	12°	0.47	0.77	0.20
	15°	0.36	–	0.22
	17°	0,07	–	0.01

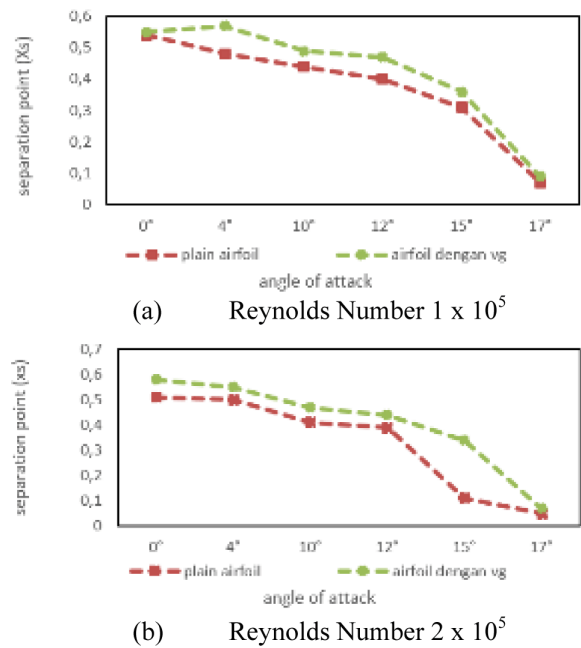
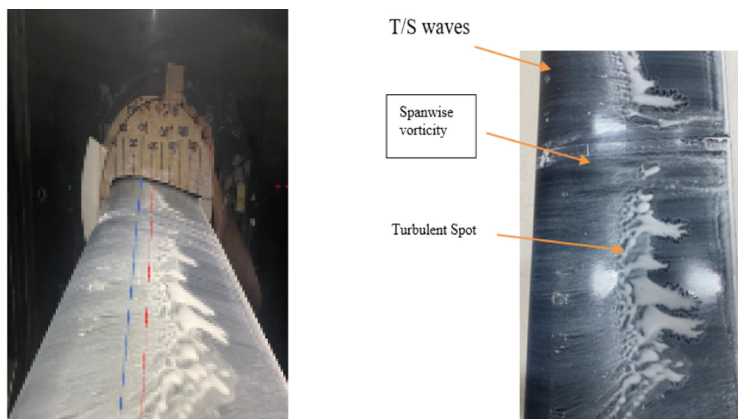


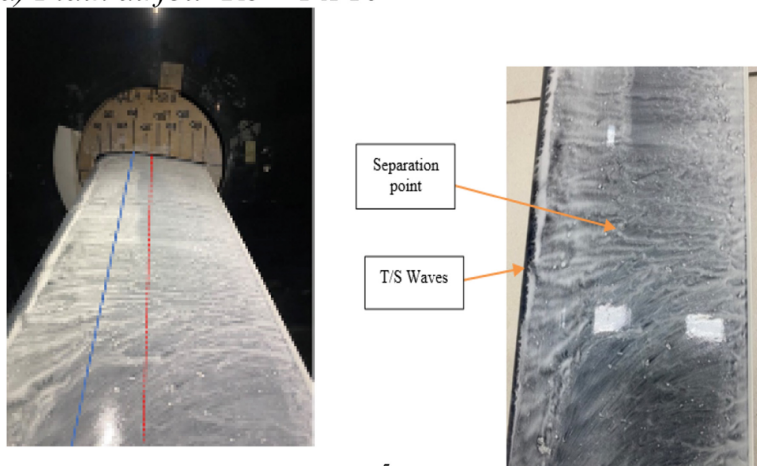
Fig. 5. Comparison of separation points (X_s) on plain airfoil and airfoil with parabolic vortex generator

With the addition of VG at the angle of attack $\alpha = 0^\circ$, the air passing through the top surface as a result of the wind tunnel, wing NACA 43018 with the installation of PVG (parabolic vortex generator) has a higher speed than plain airfoil. As seen in the figure, the changing velocity will form a line indicating the result of the PVG placement momentum which can overcome the flow separation at the trailing edge.

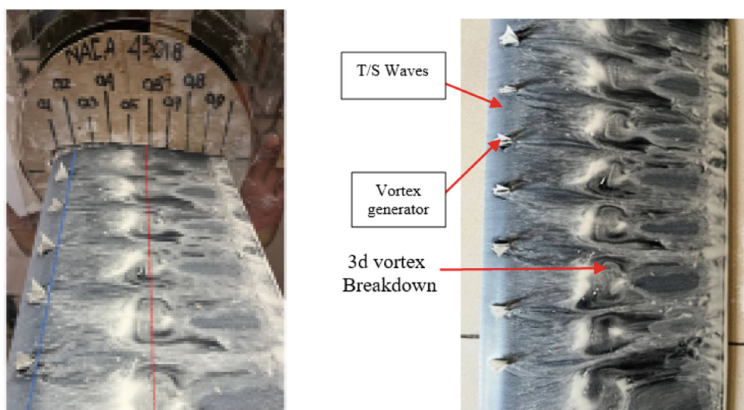
On the airfoil NACA 43018, with the angle of attack $\alpha = 4^\circ$, there has been a difference in flow on the upper surface from an angle of attack of $\alpha = 0^\circ$, this is because the flow with angles of attack of $\alpha = 0^\circ$ and 4° still follows the wing surface resulting in a higher drag from the PVG (parabolic vortex generator). At an angle of attack of $\alpha = 4^\circ$, the airfoil with the addition of a parabolic vortex generator has a larger ratio than the plain airfoil and will be more efficient as the angle of attack increases until the angle of attack is $\alpha = 12^\circ$ (Fig. 6).



(a) Plain airfoil $Re = 1 \times 10^5$

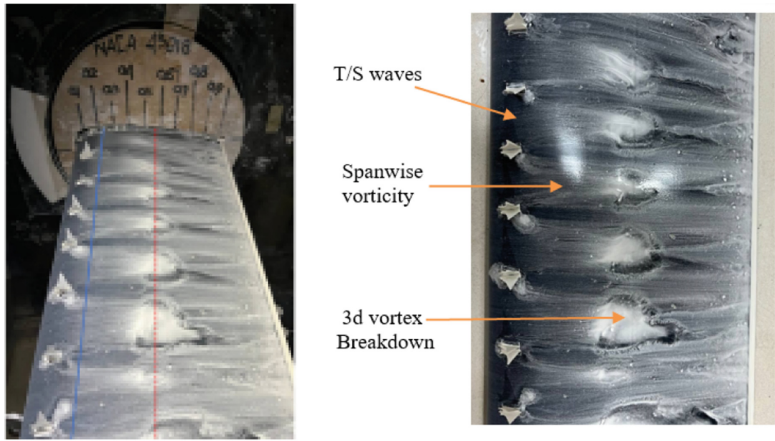


(b) Plain airfoil $Re = 2 \times 10^5$



(c) VG $Re = 1 \times 10^5$

Fig. 6. Visualization of upper surface airfoil flow with the angle of attack $\alpha = 0^\circ$



(d) $VG \text{ Re} = 2 \times 10^5$

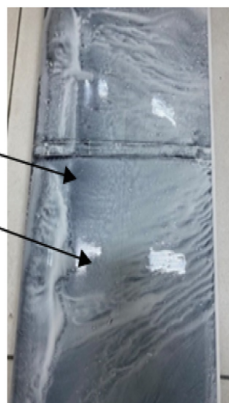
Fig. 6. (continued)

NACA 43018 with an angle of attack of $\alpha = 10^\circ$ with the application of PVG (c) and (d) visible reattach flow (air circulation can return to the top surface) to give a more streamlined impact on the surface increasing in C_L (Fig. 7).



Stagnation
point

Separation
point



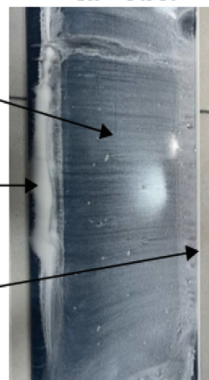
(a) *Plain airfoil* $Re = 1 \times 10^5$



spanwise
vorticity

Stagnation
point

Fully
turbulent
flow



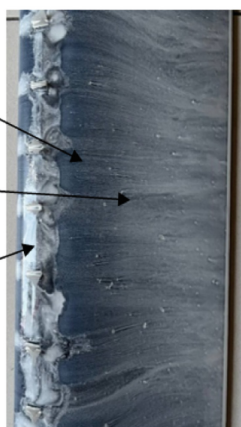
(b) *Plain airfoil* $Re = 2 \times 10^5$



T/S Waves

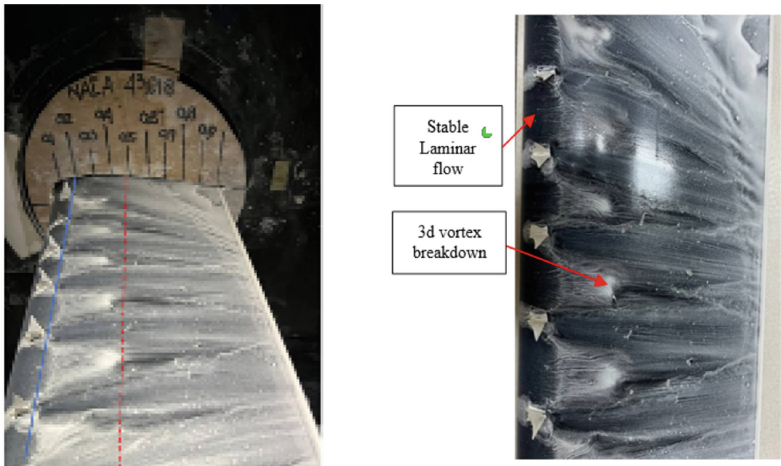
Turbulent
spot

Stagnation
point



(c) *VG* $Re = 1 \times 10^5$

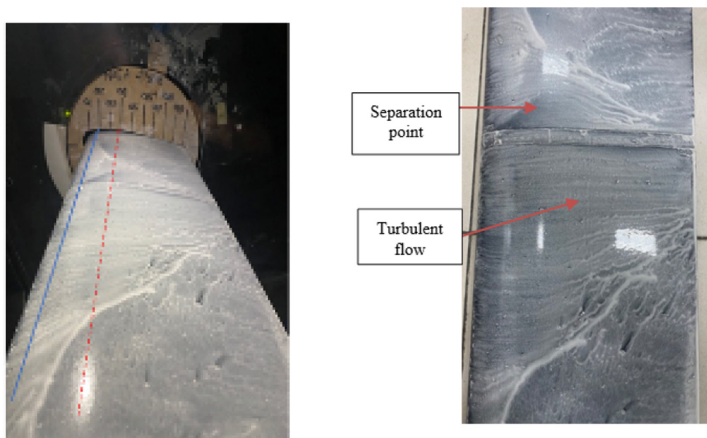
Fig. 7. Visualization of upper surface airfoil flow with the angle of attack $\alpha = 10^\circ$



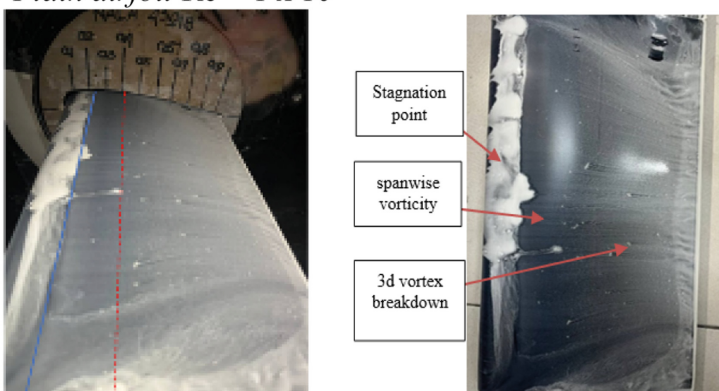
(d) $VG \text{ Re} = 2 \times 10^5$

Fig. 7. (continued)

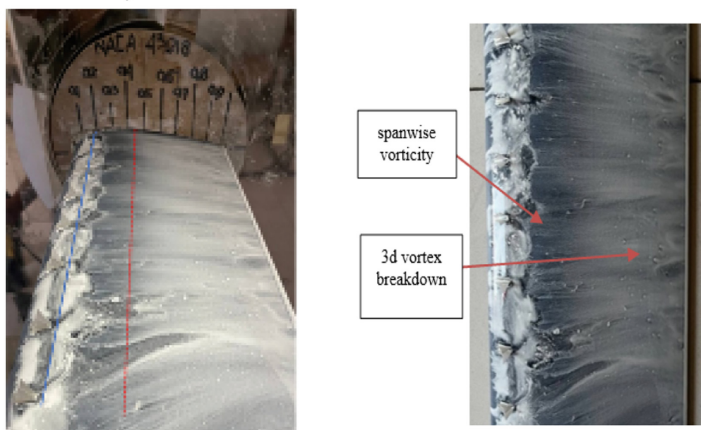
In Fig. 8, it shows the upper surface with air flowing AoA 12° on the plain airfoil (a), (b), (c) and (d) the flow separation has decreased (forward) due to the flow being hit by the airfoil, at the leading edge shown in this picture. In the wing NACA 43018 with $\alpha = 12^\circ$ PVG as shown in (c) and (d), the reattach flow is still visible.



(a) Plain airfoil $Re = 1 \times 10^5$



(b) Plain airfoil $Re = 2 \times 10^5$



(c) VG $Re = 1 \times 10^5$

Fig. 8. Visualization of upper surface airfoil flow with the angle of attack $\alpha = 12^\circ$

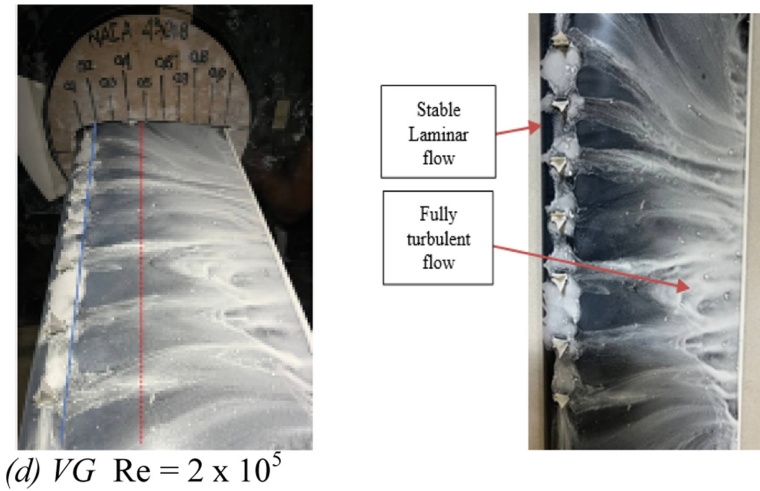
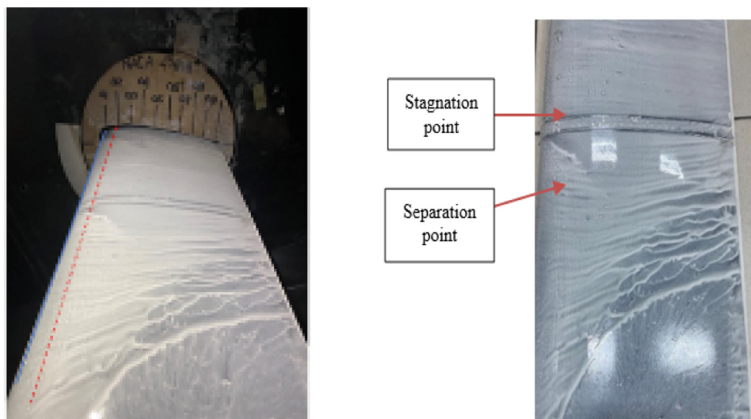
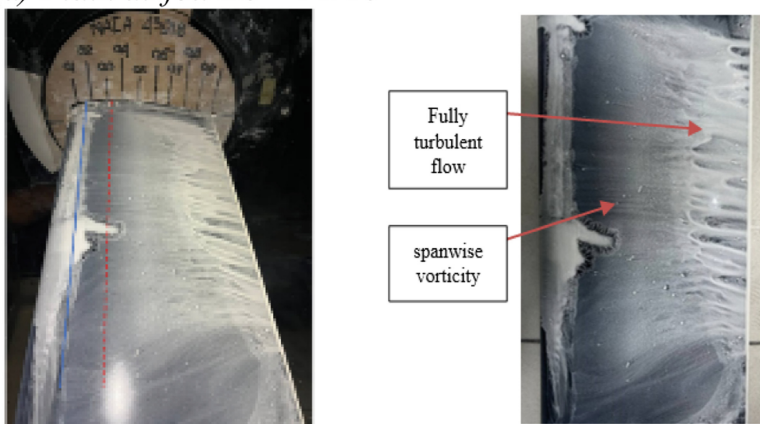


Fig. 8. (continued)

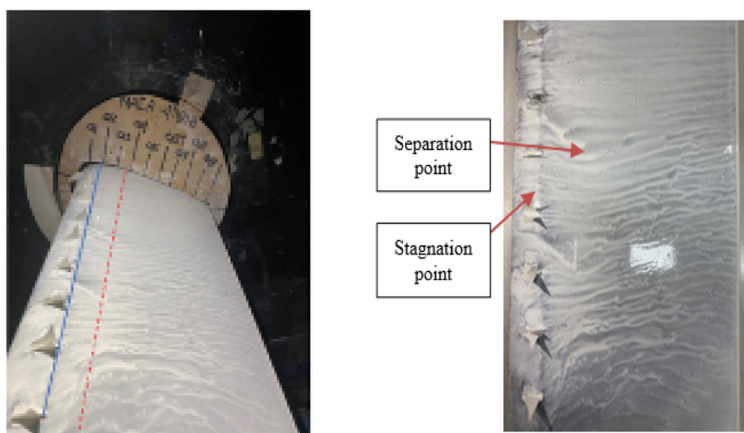
In Fig. 9, it shows the results of the upper surface airfoil with an angle of attack (AOA) of $\alpha = 15^\circ$ using a parabolic vortex generator, the flow separation value is 0.3 from the leading edge and the flow separation value in the airfoil without a vortex generator is 0.2 from the leading edge. The flow separation value on the airfoil without a vortex generator has reached a critical point and is close to the condition of an aircraft regarding the loss or reduction of lift force which can be called a stall.



(a) Plain airfoil $Re = 1 \times 10^5$

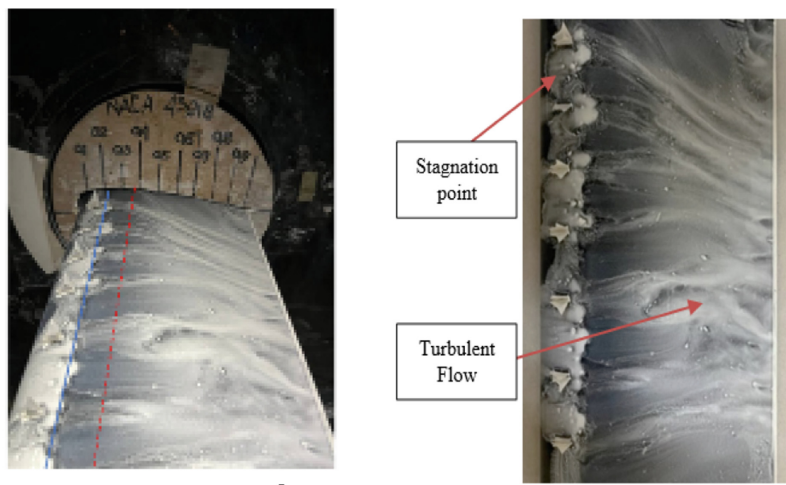


(b) Plain airfoil $Re = 2 \times 10^5$



(c) VG $Re = 1 \times 10^5$

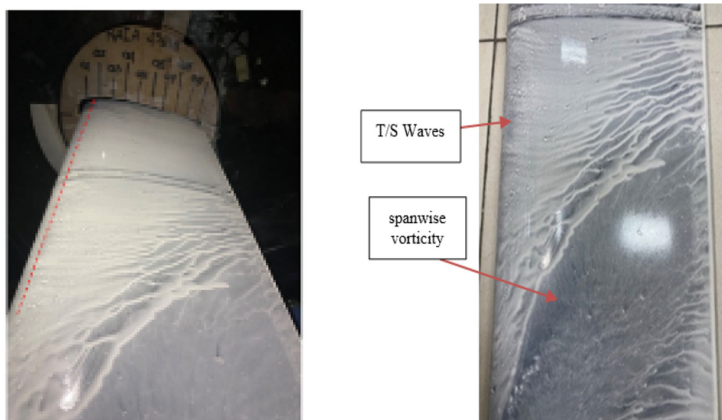
Fig. 9. Visualization of upper surface airfoil flow with the angle of attack $\alpha = 15^\circ$



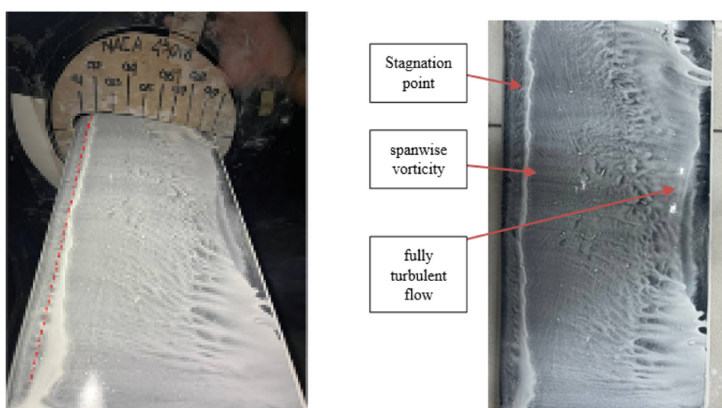
(d) $VG \text{ } Re = 2 \times 10^5$

Fig. 9. (continued)

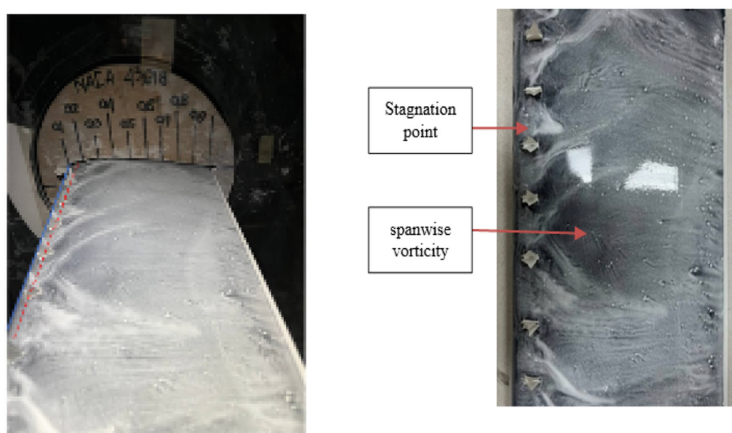
The application of the parabolic vortex generator at NACA 43018 and Plain airfoil at AoA $\alpha = 17^\circ$ has experienced a great separation point at the leading edge. This is based on the visual results of observations on the upper surface airfoil with an angle of attack of $\alpha = 17^\circ$ using a parabolic vortex generator, the separation value is 0.02 from the leading edge and the separation point value in the airfoil without a vortex generator is 0.01. The characteristics of the fluid formed in the airfoil with a vortex generator have shown the critical point limit of an airfoil condition, especially NACA 43018. Different speeds also affect and have an impact on the separation point that occurs in the airfoil (Fig. 10).



(a) Plain airfoil $Re = 1 \times 10^5$

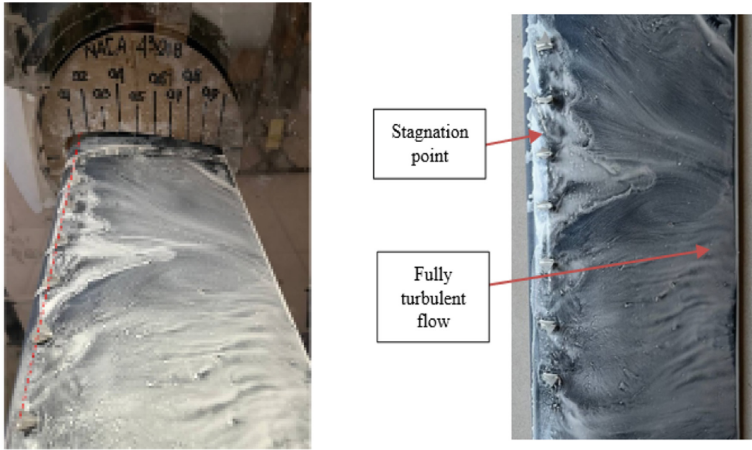


(b) Plain airfoil $Re = 2 \times 10^5$



(c) VG $Re = 1 \times 10^5$

Fig. 10. Visualization of upper surface airfoil flow with the angle of attack $\alpha = 17^\circ$



(d) $VG \text{ } Re = 2 \times 10^5$

Fig. 10. (continued)

4 Conclusion

It is known that the experimental results on the NACA 43018 airfoil and the results of oil flow visualization on the upper surface with no and the addition of VG using the WT-60 subsonic wind tunnel simulation, the conclusions can be drawn, namely:

1. The application of PVG (parabolic generator vortex) on NACA 43018 fluid momentum to counter adverse pressure gradient and surface shear stress can be increased.
2. The application of PVG (parabolic Generator vortex) can shorten the distance between the reattachment point and the separation point compared to plain Airfoil on the second Reynolds number (Re), and the application of PVG is effective when used at an angle of $AoA \ 0^\circ$ to $AoA \ \alpha = 12^\circ$.
3. The application of PVG (Parabolic Generator Vortex) at NACA 43018 can accelerate the transition from the laminar boundary layer to the turbulent boundary layer, fluid flow passing through the upper surface airfoil with PVG installation has a higher speed than plain Airfoil.

References

1. S.B. Kharge, N.C. Ghuge, V.S. Daund, Experimentation using delta winglet type vortex generator attached on tube surface of tube in tube heat exchanger for heat transfer augmentation, *Int. J. Curr. Eng. Technol.* 5 (2011) 398–402. <https://doi.org/10.14741/ijcet/22774106/spl.5.6.2016.74>.

2. C.M. Velte, M.O.L. Hansen, V.L. Okulov, Multiple vortex structures in the wake of a rectangular winglet in ground effect, *Exp. Therm. Fluid Sci.* 72 (2016) 31–39. <https://doi.org/10.1016/j.expthermflusci.2015.10.026>.
3. E.Q. Hussein, H.N. Azziz, F.L. Rashid, Aerodynamic Study of Slotted Flap for Naca 24012 Airfoil by Dynamic Mesh Techniques and Visualization Flow, *J. Therm. Eng.* 7 (2021) 230–239. <https://doi.org/10.18186/THERMAL.871989>.
4. S. Hariyadi, Studi Numerik Efek Penggunaan Vortex Generator Terhadap Boundary Layer Airfoil NACA 23018 (Studi Kasus Peletakan Vortex Generator $x/c = 10\%$, Rectangular Stright Flat Plate), 23018 (2015).
5. A.J. Pierce, F.K. Lu, D.S. Bryant, Y. Shih, New developments in surface oil flow visualization, 27th AIAA Aerodyn. Meas. Technol. Gr. Test. Conf. 2010. 1 (2010). <https://doi.org/10.2514/6.2010-4353>.
6. N. Karthikeyan, L. Venkatakrishnan, Application of photogrammetry to surface flow visualization, *Exp. Fluids*. 50 (2011) 689–700. <https://doi.org/10.1007/s00348-010-0978-x>.
7. T. Liu, Extraction of skin-friction fields from surface flow visualizations as an inverse problem, *Meas. Sci. Technol.* 24 (2013). <https://doi.org/10.1088/0957-0233/24/12/124004>.
8. A. Esfahani, K. Iranshahi, M. Mani, Surface Oil Flow Visualization of a Symmetrical Airfoil at Low-Reynolds Regimes, (2014) 2–3. <https://doi.org/10.13140/2.1.5086.2402>.
9. J. Xu, P. Hrnjak, Flow Visualization and Experimental Measurement of Compressor Oil Separator, *SAE Int. J. Passeng. Cars - Mech. Syst.* 11 (2018) 377–388. <https://doi.org/10.4271/2018-01-0067>.
10. M. Eck, J. Mihalyovics, Surface Flow Visualization Techniques, (2021). <https://doi.org/10.5281/zenodo.4493409>.
11. B. He, G. Li, F. Zhou, D. Liu, X. Xiang, Application of colour fluorescent oil flow visualization for a high speed cavity, *J. Phys. Conf. Ser.* 1786 (2021). <https://doi.org/10.1088/1742-6596/1786/1/012049>.
12. A. Terzis, P.K. Zachos, B.A. Charnley, A.I. Kalfas, Application of oil and dye flow visualization in incompressible turbomachinery flows, *E3S Web Conf.* 345 (2022) 02003. <https://doi.org/10.1051/e3sconf/202234502003>.
13. S.H. Suranto Putro, A.S. Prabowo, Studi Numerik Penggunaan Vortex Generator Pada Wing Airfoil Naca 43018, *J. Penelit.* 4 (2019) 67–77. <https://doi.org/10.46491/jp.v4e3.303.67-77>.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

