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Study of Vortex Generator Effect on Airfoil Aerodynamics Using the Computational Fluids Dynamics Method

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Abstract. The lift force is one of the important factors in supporting the aircraft flying capabilities. The airplane has a section called the aircraft wing. In particular, the wing section of aircraft is called the airfoil. One of the efforts to increase the lift force is to make the flow of air fluid at the top of the airfoil more turbulent. Turbulent flow can attract momentum from the boundary layer, the result of this momentum transfer has energy that is more resistant to the adverse pressure gradient which can trigger the flow separation. Efforts that can be made to reduce separation flow and increase lift force are the addition of a turbulent generator on the upper surface of the airfoil, one type of turbulent generator is a vortex generator, a vortex generator can accelerate the transition from the laminar boundary layer to the turbulent boundary layer. This study was conducted with the aim of knowing the effect of the vortex generator on the aerodynamics of NACA-4412 using the computational fluid dynamics method. The main thing that will be investigated is the effect of the straight type vortex generator application on the lift coefficient, by comparing the plain airfoil and airfoil that has been applied to the vortex generator to vary the angle of attack. The variation of the angles of attack are 0º, 5º, 10º, 15º and the placement of the vortex generator is 24% of the leading edge. The results obtained that the lift coefficient changes with increasing angle of attack and the application of a vortex generator to an airfoil can increase the lift coefficient than a plain airfoil. The optimum increase in lift coefficient is at the angle of attack of 5º as much as 13%.

Keywords: Computational Fluid Dynamics, Vortex Generator, Airfoil, Angle of Attack

Introduction

Various studies on aircraft parts for flight optimization were carried out. Aircraft construction is generally divided into several major parts such as the wings (hereinafter referred to as airfoils), body, and tail. In particular, an airfoil is a very important part of the aircraft's flying ability. This flying ability is closely related to the ability of the aircraft's lift, which is determined by the airfoil design. There are 4 forces that are generally involved and determine aircraft performance, namely lift, drag, stall and thrust forces. The lift force plays an important role in lift for an airplane. The lift force occurs due to higher pressure on the lower surface of the airfoil and low pressure on the upper or upper surface of the airfoil. After passing the leading edge position at the front of the plane behind the air fluid flow becomes faster but after passing the top of the airfoil the flow slows down. When the flow momentum is unable to overcome the adverse pressure gradient, a separation flow occurs around the airfoil which can cause the aircraft to lose its lift force. The lift force on the airfoil is known to be influenced by the angle of attack (hereinafter written AoA) of the airfoil. Airfoil has unique characteristics for each type, so proper

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research is needed for the use of airfoils according to the application. Currently, aircraft research uses a lot of simulation methods to determine the optimum conditions [8].

The position of AoA is very important to be studied, because when AoA is at its optimum condition, the lift force will be maximized and this has a good impact on aircraft efficiency and can delay the separation flow so that the lift force becomes even greater. Too high an airfoil position can make the pressure in the upper space of the airfoil low and trigger flow separation. The existence of separation flow is very detrimental because the separation flow causes the lift force to decrease. Flow separation events can occur especially when the angle of attack is high. Therefore, airfoil modification must be done in various ways, for example, the most common method is to use a vortex generator. This vortex generator can be added to the airfoil which will be able to modify the separation flow so as to increase the lift force [5].

A vortex generator is an object that is used to modify the air flow around an airfoil with various specific shapes. One of them is in the form of a fin or fin which can accelerate the transition from a laminar boundary layer to a turbulent boundary layer. During the turbulent boundary layer, the velocity of the fluid closest to the surface will have a value greater than that of the boundary laminar layer. The greater the fluid velocity will have an impact on the kinetic energy of the fluid which will also increase, so that it can fight against the adverse pressure gradients [5].

The article conducts a study to determine the aerodynamic characteristics of the aircraft (wing) on plain airfoils and airfoils that are given a vortex generator. In this study, the airfoil model used was NACA-4412 with a triangular vortex generator type vortex generator. This research uses NACA-4412 because this model is quite popular in airplane design tutorials. The main analysis in this research is to compare the lift coefficient on plain airfoil and modified airfoils with a vortex generator. Researchers used a NACA-4412 airfoil and triangular type vortex generator to determine aerodynamic characteristics. Aerodynamic characteristics studies with the addition of the airfoil vortex generator NACA-4412 will be carried out using CFD (Computational Fluid Dynamics) software simulation, namely Solidworks. The use of Solidworks in this study will be very useful for simulating aircraft fluid flow and knowing the impact that occurs by including physical variables such as angle of attack and wind speed in the simulation input.

Materials and methods

Airfoil

Airfoil is something that when placed in a fluid flow will produce a lift force. The lift or lift force occurs because the shape of the top of the airfoil is curved which causes the fluid to flow above the airfoil faster, when the fluid flows faster, the pressure will be lower. The fluid that flows under the airfoil has a velocity below the fluid flowing above the airfoil, because this is where the pressure below the airfoil is greater and a lift force is created [3].

Two major types of airfoils are symmetrical airfoils and asymmetrical airfoils. This symmetrical airfoil has the same top and bottom shape, which causes the chamber to always have a value of 0, usually this type of airfoil is placed for the tail. Symmetrical airfoil is often used as a stabilizer for aerobatics which have extreme maneuverability. Asymmetrical airfoil has an upper curve more curved than the bottom curve of the airfoil surface, this type of airfoil is the most common shape of conventional aircraft [15].

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Vortex Generator

A vortex generator is an object that is used to modify air flow by placing it on the outer surface of an object such as an airplane wing, car, windmill, or around an airfoil with various specific shapes. One of them is in the form of fins or fins. The installation of a vortex generator on the aircraft wing can make the lift on the aircraft wing more efficient, especially in large AoA before critical AoA. The vortex generator has a way of working with the system when the plane is running to break the wind in the air, the vortex generator creates a process that causes data to move from the laminar boundary layer to the turbulent boundary layer due to the transfer of momentum [3].

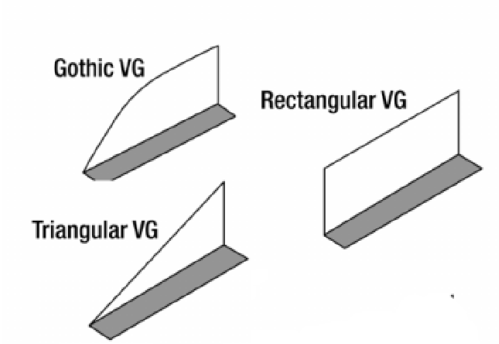

Figure 1.Type of vortex generator [7]

The three major forms of vortex generators commonly used in aerodynamics, the first is the Gothic VG form, the second is the VG rectangular shape, the third is the triangular VG. Comparisons were made to these three types of Virtual Generators and the results of the analysis gave a drag value of 0.008797 for rectangular VG, 0.006990 for Gothic VG, and 0.0022062 for triangular VG at AoA 0°. The triangular type vortex generator provides the best drag force reduction of the other two forms [7].

Angle of Attack

Angle of Attack is the angle formed by the direction of air flowing on an airfoil and bowstring on an airfoil. AoA is usually written with the notation α. The air flow will flow on the airfoil and form a negative angle, this causes the angle of attack to have zero lift, this condition is called zero lift angle [9].

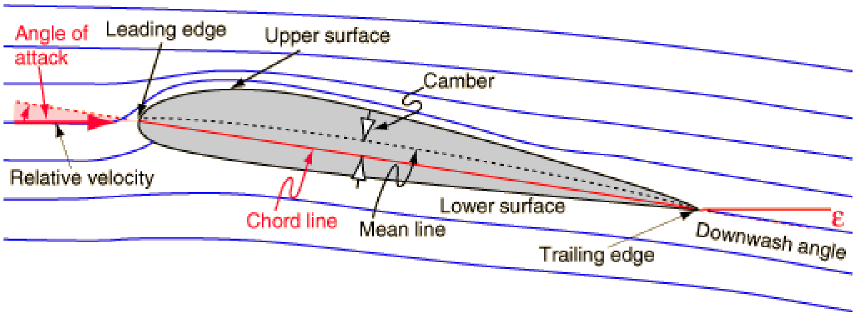

Figure 2. Wing Cross Section [8]

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Flow on the Airfoil

Air flow on an airfoil is divided into three types, namely laminar flow, transition flow, and turbulent flow. Liquid / gas particles in laminar flow move in a regular and parallel path. Laminar flow occurs when the viscosity is large or the velocity is low [2].

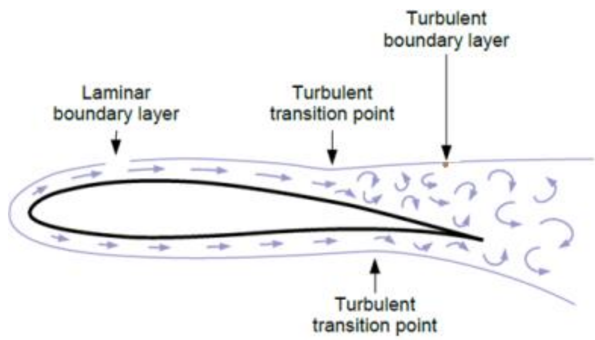

Figure 3. Flow on the Airfoil [2]

Fluid viscosity has a major influence in reducing disturbances that result in turbulent flow. When the viscosity decreases and there is an increase in flow velocity, the damping power to the disturbance is reduced, to some extent it can cause a change in flow, namely changing the laminar flow to turbulent flow. In the turbulent flow, the gas or liquid particles move irregularly. Turbulent flow occurs when the gas or liquid is small and at high velocity [11].

CFD (Computational Fluid Dynamic)

CFD (Computational Fluid Dynamics) is a set of methodologies used so that computers can display a numerical simulation of fluid flow. The system that occurs in CFD uses a mathematical model which is transformed into a virtual form so that it can be visualized. Broadly speaking, there are three stages in the CFD simulation process [3].

The pre-processing stage is the part where the process of defining the geometry of the airfoil model will be simulated into a computational domain that can be processed by computer. Create constraints for the simulation of airfoils. **Defining the fluid to be used and other variables**: The solver stage occurs in a numerical computation process using the equations used for CFD simulations. The Navier-Stokes equation is the basis that is always used in CFD flow simulations. This equation is represented by the geometry formed by flow acceleration and pressure. The Navier-Stokes equations are always solved by the continuity equation, based on the principle of momentum, when the continuity equation represents the conservation of mass. This equation can be used for each flow point and shows all the details of the flow that can be solved in the flow area. However, many of the differential equations of fluid mechanics are too difficult to solve and require the help of computers [3].

This post-processing stage of numerical computation results is displayed and documented. This visualization is useful for analysis. In addition, you can also see the velocity contours on the airfoil [3].

Formula

The Navier-Stokes equation is the basis for almost all CFD (Computational Fluid Dynamics) flow modeling. This equation predicts the velocity of a fluid and its pressure in a given geometry. The

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Navier-Stokes equations are always solved together with the continuity equation. The Navier-Stokes equation serves as a conservation of momentum, while the continuity equation represents conservation of mass. This equation is valid for any point in the flow and thus all details of the flow can be solved anywhere in the flow domain. However, most of the differential equations in fluid mechanics are very difficult to solve and therefore often require assistance from computers. This equation in certain cases may need to be combined with additional equations, such as the energy equation. Navier-stokes formula shows at the equation below [6].

$$\rho \frac{\delta v}{\delta t} = -\nabla p + \rho g + \mu \nabla^2 v \quad (1)$$

Results and discussion

Below is a graph table for plain airfoil and airfoil with the addition of a vortex generator for AoA variations.

Table 1. Lift coefficient data on airfoil with vortex generator and plain airfoil

Angle of Attack	*Vortex generator* *Lift Coefficient*	*Plain airfoil* *Lift Coefficient*
0	0.1699	0.1549
5	0.3403	0.3178
10	0.543	0.5308
15	0.7749	0.7754

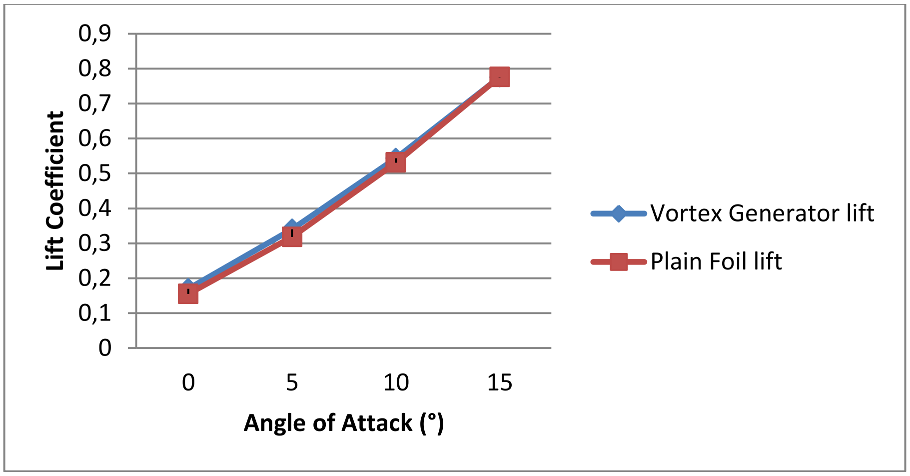

Figure 4. Lift coefficient graph against AoA

Table 2. The result of the percentage difference in lift coefficient

Lift coefficient Airfoil with *vortex generator*	*Lift coefficient* Plain Airfoil	Different *lift coefficient*	Percentage
0.1699	0.1549	0.015	8.83%
0.3403	0.3178	0.0225	13.24%
0.543	0.5308	0.0122	7.18%
0.7749	0.7754	0.0005	0.29%

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The graph above shows that the use of a vortex generator can increase the lift coefficient. Airfoil with AoA 5° displays a red area that is larger than at a 0° angle, this is because changes in AoA, AoA 5° are more effective in maximizing the potential of the vortex generator. Momentum is drawn from the boundary layer because of the vortices caused by the application of the vortex generator, therefore the energy around the vortex generator is getting bigger and can withstand adverse pressure gradient and can delay the flow of separation which can trigger a stall. The rapid air dispersion in the upper space causes the pressure to be smaller than the lower surface. This results in an increase in lift force.

The increase in lift coefficient affects the airfoil lift. A significant lift coefficient comparison between plain airfoil and airfoil with vortex generators is at an angle of attack of 5° with a difference of 13%. The behavior of the vortex generator with the specifications of the leg dimensions 0.18 cm thick, 4.5 cm wide, 10 cm long, and the fin dimensions 10 cm long, 4.5 cm high, 0.25 cm thick with straight-type arrangement is given to the NACA airfoil -4412, the specification of the airfoil is 400 cm long, 200 cm wide, and the placement of the vortex generator on the airfoil is 24% of the leading edge. Of course, the results obtained are relatively different if the vortex generator applied to the airfoil has different dimensions.

Conclusions

Based on the research results, it can be concluded in the form of. The increase in lift coefficient is directly proportional to the increase in angle of attack. Based on the simulation results for the NACA-4412 airfoil, a significant increase in lift coefficient between plain airfoil and airfoil with the vortex generator at an angle of attack of 5°.

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