Mekanika: Majalah Ilmiah Mekanika

CFD Modeling of Narasena Bengawan UV Team Quickster UAV Wingswith Addition of Vortex Generator to Aerodynamic Performance

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Abstract
This research is based on obtaining the best possible aerodynamic performancefor the Quickster Narasena Bengawan UV Team Unmanned Aerial Vehicle (UAV) aircraft wing design. One factor that significantly affects the flying version of a UAV is the wing. The Quickster Narasena UAV aircraft wing uses an MH33 airfoil because MH33 is specifically for high-speed UAV aircraft. This research will compare the performance of a branch without a vortex generator with addition with a vortex generator. This study will also discuss variations in the positioning of the vortex generator on the wing of the Quickster Narasena UAV. The method used in this research is the Computational Fluid Dynamics (CFD) method. The simulation process will use the ANSYS Fluent 19.0 application with the K-Omega Shear Stress Transform (SST) method with the Reynolds-Averaged-Navier-Stokes (RANS) equation as the basis. This study aims to obtain the results of the coefficient of drag, lift, and the contour of the turbulencethat will occur. The simulation results that have been done are the geometry of the wing with the addition of a vortex generator can reduce the drag coefficientand can increase the lift coefficient.

1 Introduction

Unmanned Aerial Vehicles (UAVs) is a flying vehicle controlled remotely by the pilot or can move automatically according to the parameters entered in the control system [1]. UAVs have been widely used in several fields to facilitate human work. In the field of education, UAVs have begun to enter and develop among universities globally, and it has even become a competition between universities [2]. Bengawan UV Team is an unmanned vehicle research team focused on UAVs and Unmanned Surface Vehicles (USVs) at Sebelas Maret University, aiming to research, design, and build unmanned vehicles for any required mission. Every year the Bengawan UV Team participates in the *Kontes Robot Terbang Indonesia* (KRTI) competition. Besides that, the Bengawan UV Team has also been involved in the business of photo mapping and monitoring services in an area. Therefore, it is necessary to consider the initial design phase related to the emphasis on the aerodynamics of the drone that will be made [4].

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In considering the aerodynamic aspects of UAV aircraft, it is influenced by fuselage design, wing design, stability and control studies, empennage design, and cooling inlet, all of which are included in his consideration [3]. Considering the initial design phase, it can shorten the processing time, reduce the trial-and-error phase, and achieve the desired goal. A Vortex Generator (VG) is a small fin-shaped component placed on the wing surface that aims to modify the flow around the surface, creating a boundary layer to delay flow separation and stall [5]. A vortex generator is one type of turbulent generator that can control rough boundary layer separation[9]. They are designed to produce a streamwise vortex that energizes the near-wall laminar flow to overcomethe adverse gradient [8].

Previous studies discussed the addition of a vortex generator and the influence of the placement and height of the vortex generator on the development of the turbulent boundary layer so that it can improve wing performance [6]. The airfoil used is NASA LS-0417 with *Re* 1.41 x 10^5 on Angle of Attack (AoA) 16°, and the type of vortex generator used is counter-rotating. Then the parameters used are the variation of the height of the vortex generator (*h*), namely at *h* = 1, 3, and 5mm, and the variation in the placement of the vortex generator from the leading edge (*x/c*), namely 0.1; 0.2; 0.3; and 0.4. Overall, the results of this study are that the most optimal vortex generator variations are *x/c* 0.3 and *h* = 1 mm, where the Coefficient Lift (CL) / Coefficient Drag (CD) value has increased by 14.337%.

This research will focus on developing the wing design of the Quickster Narasena Bengawan UV Team UNS aircraft. The development of the wing structure in this study includes a part of the wing configuration that will be used to add a vortex generator with a variation of the position of the vortex generator on the Quickster Narasena Bengawan UV Team UNS aircraft wing. With this development, it isexpected to get good aerodynamic results.

2 Experimental Methods

In making the Quickster Narasena Bengawan UV Team UNS aircraft, an initial design was needed to support the success of winning the race. Then in the selection of airfoils, this study uses an MH33 airfoil. The MH33 airfoil is specifically for UAV aircraft at high speed. In this paper will discuss 6 variations of wing, wing without VG; wing with VG 0.1 *x/c*; wing with VG 0.2*x/c*; wing with VG 0.3 *x/c*; wing with VG 0.4 *x/c*; and wing with VG 0.5 *x/c*. The following (see Table 1 and Figure 1) is the geometryof the Quickster Narasena Bengawan UV Team UNS aircraft wing:

Table 1. Quickster wing geometry

Geometry Wing of UAV Aircraft Quickster Narasena	
Parameters	**Value**
Chord root	369 mm
Chord tip	111 mm
Wing span	1,400 mm
Wing area	336,000 mm²
Aspect ratio	5.83
Taper ratio	0.3
Configuration	High Wing

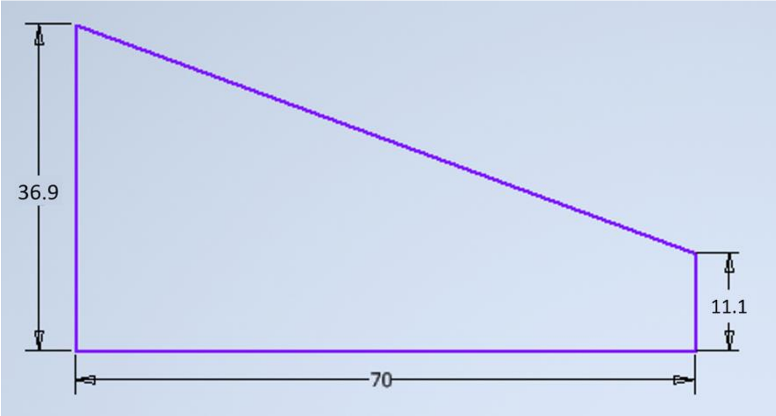


Figure 1. Quickster wing geometry

This study also uses the addition of a vortex generator design. The choice of vortex generator designs based on research conducted by Azmi and Sasongko [6]. In a study by Azmi and Sasongko [6], a counter-rotatingvortex generator has better efficiency than other vortex generators. The following (see Table 2-Figures 2 and 3) is the geometry of the vortex generator that will be used:

Table 2. Vortex generator geometry

Vortex Generator Geometry	
Parameters	**Value**
A fin spacing of VG (*d*)	5 mm
Length of VG (*l*)	7.5 mm
Orientation angle to the free stream velocity	10°
Height of VG (*h*)	1 mm
Width of VG	1 mm

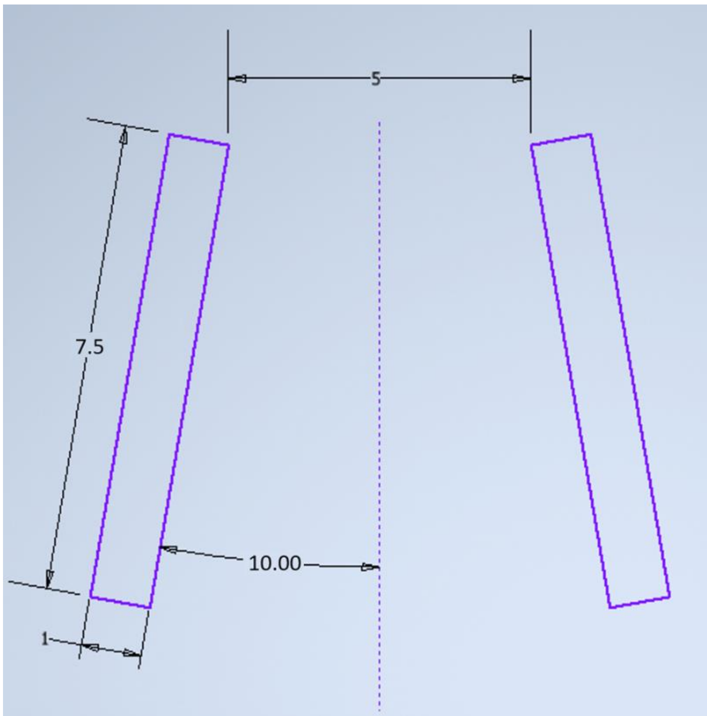


Figure 2. Vortex generator geometry

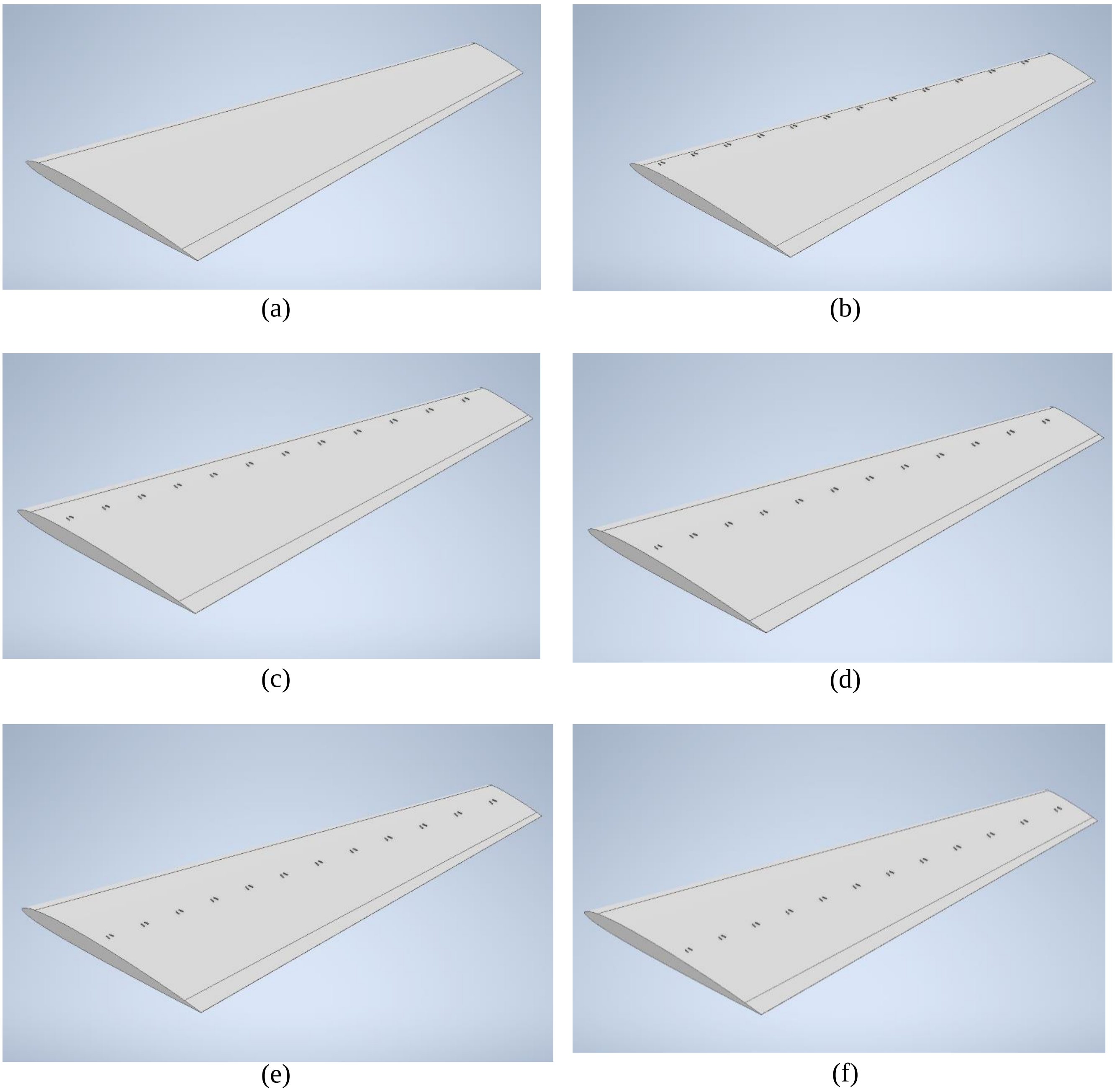


Figure 3. 3D modelling Quickster wing (a) No VG, (b) VG 0.1 *x/c*, (c) VG 0.2 *x/c*, (d) VG 0.3 *x/c*, (e) VG 0.4 *x/c*, and (f) VG 0.5 *x/c*

In this paper, the fluid flow will be assumed to be a steady flow, viscous, incompressible, and isothermal using the Reynolds-Averaged-Navier-Stokes (RANS) equation. Then, the calculation method to complete this research is the turbulence model with the k-omega SST method because the k-omega SST method can capture turbulence and vortex phenomena better than the split-all mara's method.

2.1 Steady flow

The fluid flow, which is assumed to be steady, is when all properties in the flowing fluid do not change with time (t) [13] as shown in Equation 1.

$$\frac{\partial V}{\partial t} = 0 \text{ atau } V = V\ (x, y, z) \tag{1}$$

2.2 Incompressible flow

Flow in which the density value (ρ) is constant is called incompressible flow or cannot be compressed along with the flow (see Equation 2).

$$\frac{\partial \rho}{\partial x} = 0\ ; \frac{\partial \rho}{\partial y} = 0; \frac{\partial \rho}{\partial z} = 0 \quad (2)$$

2.3 Continuity equation

The assumptions are related to steady flow then the amount of mass in the control volume will be constant or constant (see Equation 3).

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (3)$$

2.4 Conservation of momentum

The law of conservation of momentum is expressed by the Navier-Stokes equation, which is an equation derived from Newton's second law. In this study, it is assumed that the fluid flow is in a steady flow and incompressible flow conditions so that it can be simplified as show in Equation 4.

$$\begin{aligned} x;\ \rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) &= -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \\ y;\ \rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) &= -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) \\ z;\ \rho\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) &= -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \end{aligned} \quad (4)$$

Enclosure in this study using a half-bullet shape often called the c-type domain refers to research conducted by Jin and Lee [14]. By using the following boundary conditions (see Figure 4):

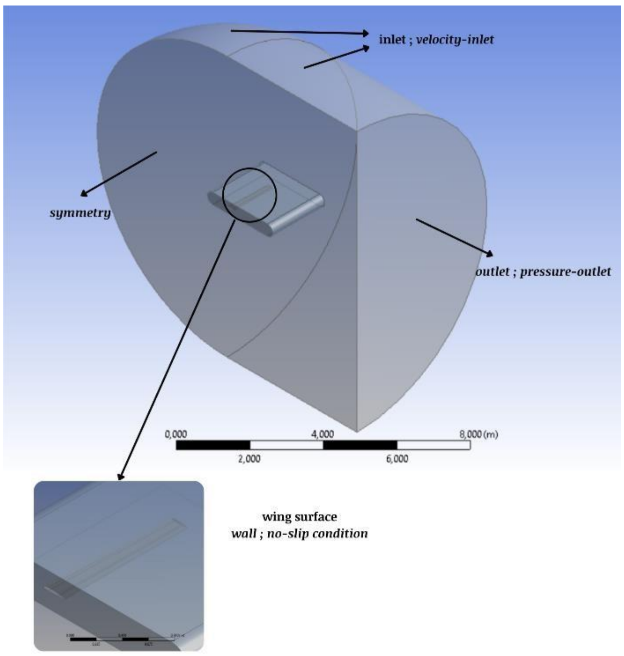


Figure 4. Boundary condition

In this paper, the validation method refers to Narayan and John [7]. As the result of this validation, the error percentage level obtained is 6-7%. These results were obtained after going through the Grid Independency Test (GIT) process, which was carried out to find a method that could be more efficient and produce the slightest error. M3 was chosen as the method to be used as the basis for validation. Furthermore, the methods that have been carried out at the validation stage will be used to find the research results to be carried out (as shown in Tables 3 and 4).

Table 3. Grid independence test validation

Meshing	Element	CL	CL Error (%)	CD	CD Error (%)
Base	-	0,47	-	0.022	-
M1	5,022,451	0.50202	6.8128%	0.02362	7.3591%
M2	3,553,180	0.51483	9.5383%	0.02216	0.7318%
M3	6,942,034	0.5047	7.3830%	0.02336	6.1636%
M4	7,445,462	0.50439	7.3170%	0.02342	6.4409%
M5	5,932,933	0.50259	6.9340%	0.02358	7.2000%

Table 4. Quality of meshing

Quality of Meshing		
Parameters		**Value**
Nodes		2,445,434
Element		6,942,034
Orthogonal	**Min**	0.09635
	Average	0.77287
	Max	0.99942
Skewness	**Min**	0.00017
	Average	0.22653
	Max	0.90365
Aspect Ratio	**Min**	1.1684
	Average	2.2469
	Max	19.343

3 Results and Discussion

The addition of vortex generators includes five placements, namely at 0.1-0.5 *x/c* with 0.1 intervals. Then the speed that will be used is the average maneuver speed, which is 135 km/h and at AoA 8°. This isbecause to get the effect of adding an efficient vortex generator [10]. At this stage, it is to get the right location for the addition of the vortex generator to be applied to the Narasena Bengawan UV Team Quickster UAV aircraft.

3.1 Lift and drag coefficient analysis

In this lift coefficient analysis, it is hoped that adding a vortex generator can increase the winglift coefficient without a vortex generator. Then the drag coefficient becomes a consequence of the addition of the vortex generator to increase the drag [11], but the correct placement can make the drag coefficient decrease (as shown in Figure 5).

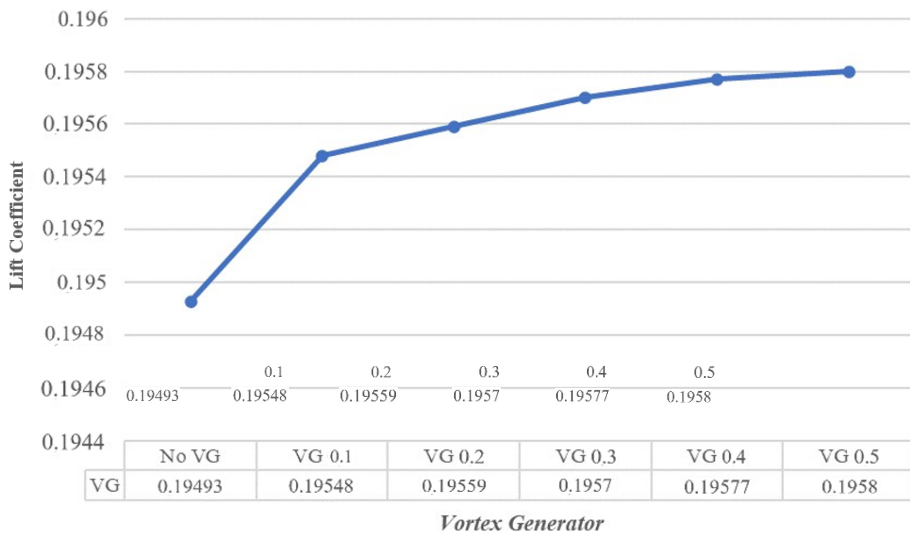


Figure 5. Graph of lift coefficient to vortex generator

In the results of the lift coefficient above, it is found that the addition of a vortex generator can increase the lift coefficient [11]. Then along with the increase in the location of the vortex generator placement, the lift coefficient also increases. This proves that using a vortex generator on an MH33 airfoil with a high angle of attack can increase the lift coefficient. These results are consistent with the research conducted by Azmi and Sasongko [6] with the addition of a vortex generator that can delay airflow separation [12] so that the lift coefficient on the wings increases at high AoA.

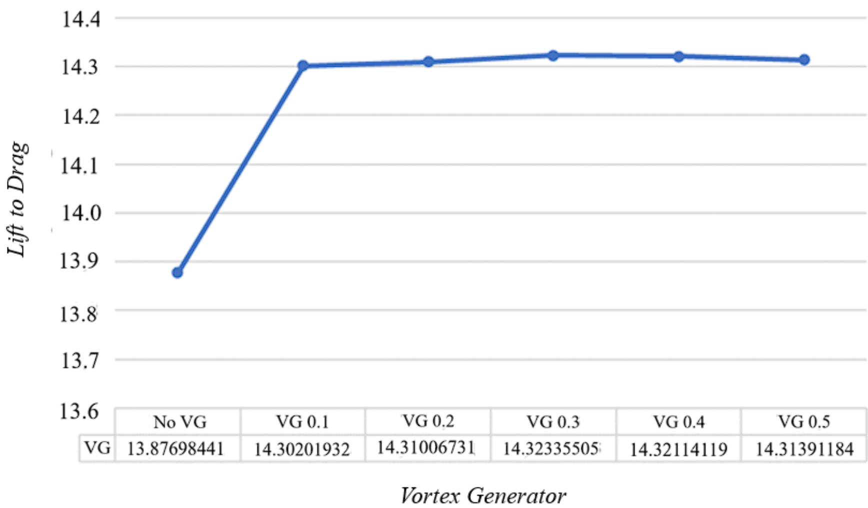
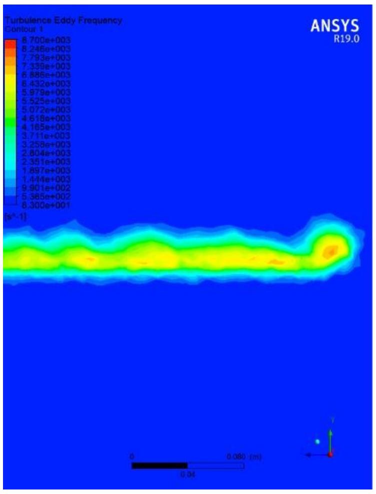


Figure 6. Graph of drag coefficient to vortex generator

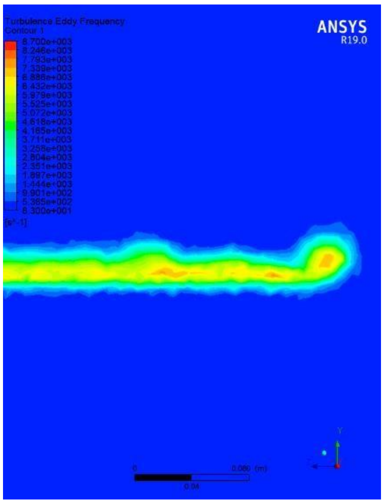
The drag coefficient graph in Figure 6 above shows a decrease in the drag coefficient with the addition of a vortex generator [6]. In the addition of a vortex generator, the most significant drag coefficient lies at the position of 0.5 *x/c* and the smallest at the work of 0.3 *x/c*. These results prove that the most appropriate placement to get the smallest drag coefficient is at the position of 0.3 *x/c*. This is supportedby the research of Azmi and Sasongko [6], that the placement of the vortex generator, which produces the smallest drag coefficient, is at 0.3 *x/c*.

3.2 Analysis of the contour of turbulence on the wing

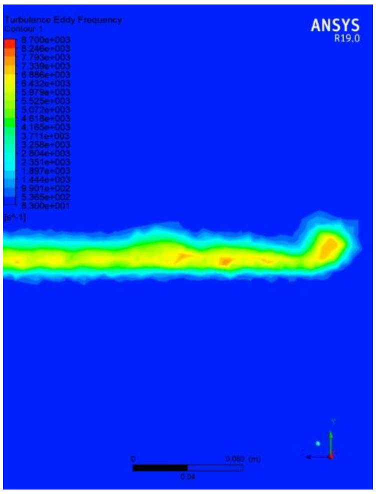
Figure 7 above shows the difference in turbulence contours between the wings without a vortex generator and the addition of a vortex generator with variations in placement. Wings without vortex, generators tend to have considerable turbulence only at the wing tips. The branch with the addition of VG can increase the turbulence along the wing [12]. This indicates that the effect of the vortex generator makes the airflow that was previously laminar and separated forced into turbulence [6]. So that in this turbulence contour, the wing, with the addition of a vortex generator, has red dots (high turbulence) in several parts of the branch of the five placements vortex generator, vortex generator 0.3 *x/c* has the highest turbulence contour.This indicates that the most appropriate placement of the vortex generator for this wing is at 0.3 *x/c*, supported by the best lift to drag results obtained at the 0.3 *x/c* station.



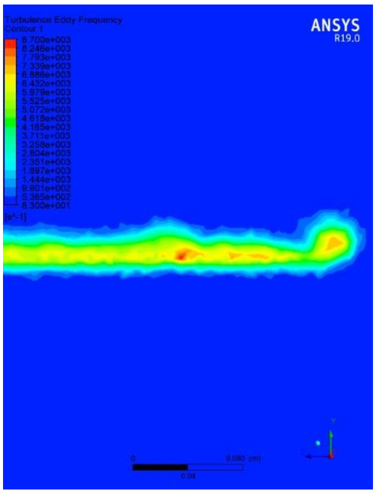
(a)



(b)

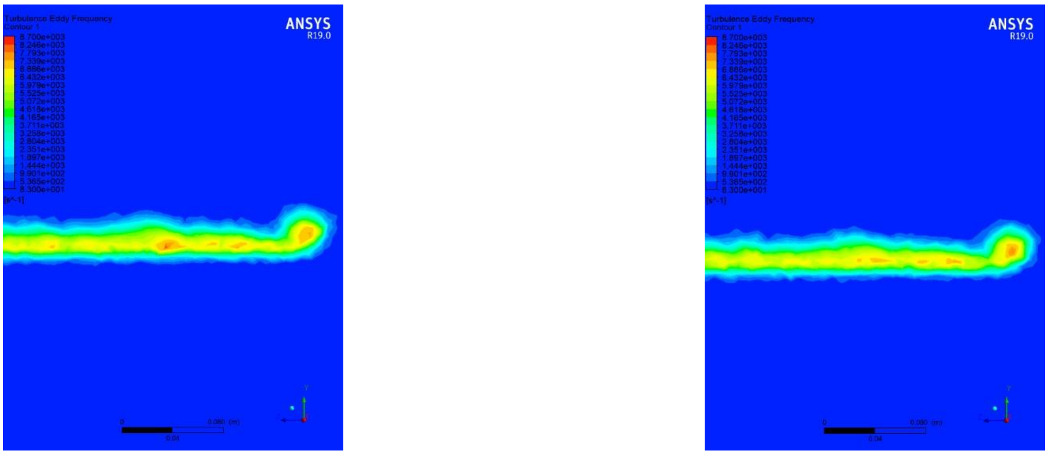


(c)



(d)

Figure 7. Contour of turbulence eddy frequency on AoA 8° (a) No VG, (b) VG 0.1 *x/c*, (c) VG 0.2 *x/c*, (d) VG 0.3 *x/c*, (e) VG 0.4 *x/c*, and (f) VG 0.5 *x/c*



(e) (f)

Figure 7. *Cont.*

4 Conclusions

The addition of a vortex generator at all locations can reduce the drag coefficient and increase the liftcoefficient on the wing at AoA 8°. The best placement of the vortex generator at 0.3 *x/c* is indicated by theresults of the most significant lift to drag and the smallest coefficient of drag obtained. As well as having the largestturbulence contours, it proves that the placement of the vortex generator is correct. The addition of a vortexgenerator can also reduce the moment coefficient because the flow separation on the wing can be delayed.

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