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Computational Analysis of The Application of Active Control on Vehicle Model with Varied Suction Velocities

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Abstract

In general, vehicles traveling at a certain speed will experience drag as a result of direct contact between fluids and the surface of the vehicle and will also experience the phenomenon of the wake due to flow separation. Low pressure that occurs at the rear of the vehicle generate wake caused by flow separation which in turns will affect vehicle performance. One of the methods that can be done to reduce drag aerodynamic of vehicles is flow control techniques. In this research, the test model used is modified Ahmed body treated by altering flow orientation of the original model. The test model is equipped with five circular holes as active control actuation placed on the upper side of the back with speeds of 0.5 m/s and 1 m/s respectively. This research was conducted through a computational approach with the standard k-epsilon turbulence model. CFD simulations were carried out at three upstream speeds of 13.9 m/s, 16.7 m/s and 19.4 m/s respectively. The results showed that the use of active control by suction had influences on wake formation, where the smallest wake formation was obtained on the test model equipped with active control by suction at a speed of 0.5 m/s. The application of active control by suction also affects aerodynamic drag, where the greatest drag reduction occurred with the values of 10.9% on the test model with a suction speed of 0.5 m/s.

Keywords: CFD, aerodynamic drag, active control, suction, wake

1. Introduction

Low pressure that occurs at the rear of the vehicle triggers a wake generated by flow separation which affects the vehicle's performance [1]. Flow that moves regularly will split when separation occurs and cause a decrease in pressure distribution and therefore will induce aerodynamic drag [2]. The main cause of aerodynamic drag on vehicles is the distribution of pressure on the rearside and surface of the vehicle. Both of these areas contribute 90% of the total drag and 80% of it occurs in the rearside of the vehicle [3]. Aerodynamic drag influences the efficiency of fuel use and exhaust gas production where around 50-60% of total fuel energy is used to overcome aerodynamics drag [4-5].

In fluid dynamics point of view, the method to reduce aerodynamic drag can be achieved by delaying separation and reducing the development of the recirculation area at the back of the dispersed vortex structure [6]. Drag reduction can also be obtained by reducing or eliminating the longitudinal vortex by reducing the area of the treated area or by limiting the total pressure drop on the area in question. The abovementioned method can be done by controlling the flow of the wall surface with an active control system. Flow control techniques that have been developed can be divided into 4 based on configuration and purpose, including: 1). Control the sliding layer at the point of separation, 2). Control the boundary layer, 3). Control by actuation along the downstream wall at the point of separation and 4). Control flow by performing actuation in the downstream region where separation occurs [7].

The use of active control especially with suction techniques has been proven through computational research capable of reducing aerodynamic drag. Among them are Lehugeur & Gillieron, where the results of the study show that the application of active suction control reduces aerodynamic obstacles close to 8% [8]. The same thing was done by Harinaldi et al who showed that the use of active suction control was able to reduce aerodynamic drag by 15.83% [9]. Placement of active control at the top of the rear window of the Ahmed body model which has a 25^0 slant angle of windshield with a diameter of 0.01 meter perforated flow control can also increase the average pressure distribution, significantly reduce flow separation and reduce aerodynamic drag by 9.4% [10].

2. Method

In this research, the test model used is Ahmed body modification by changing the flow orientation of the original model. The shape of the vehicle is modeled simply to produce features that are relevant to the flow around the real vehicle according to previous research [11-14]. The test model used has a dimension ratio of 0.17 to the original Ahmed body with dimensions of length l = 174 mm, height h = 48 mm and width w = 64.83 mm. The test model has a front geometry slant of 25^0. At the top of the rear geometry of the test model, there are five holes each of 7 mm in diameter as active suction control actuators. Each slits is defined as suction 1 (S_{c1}), suction 2 (S_{c2}), suction 3 (S_{c3}), suction 4 (S_{c4}) and suction 5 (S_{c5}) with the appropriate velocity variations shown in Tables 1, 2 and 3. The distance between holes is 10.81 mm. Details of the test model are shown in Fig. 1.

The numerical simulation in this study uses the CFD fluent 6.3 software with the standard *k-epsilon* turbulence model. In the initial stage, the test model is defined in the form of a computational domain as shown in Fig. 2 which is then made into a mesh as shown in Fig. 3. Boundary conditions applied include the upstream velocity of 13.9 m/s, 16.7 m/s and 19.4 m/s. The density of air is 1,225 kg/m^3 and viscosity is 1.7894 x 10^{-5}. Air is assumed as incompressible flow in steady state.

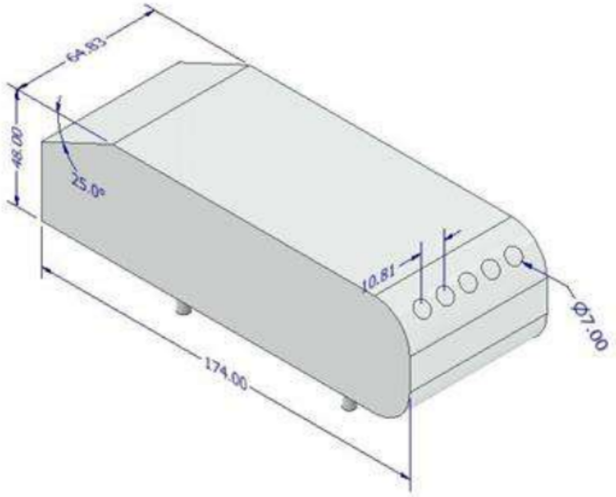


Fig. 1 Test model

Table 1. Comparison of suction speed to upstream velocity, $U_0 = 13.9$ m/s

U_0 (m/s)	S_c	U_{Sc1} (m/s)	$\frac{U_0}{U_{Sc1}}$	U_{Sc2} (m/s)	$\frac{U_0}{U_{Sc2}}$
13.9	S_{c1}	0.5	0.035	1	0.07
	S_{c2}	0.5	0.035	1	0.07
	S_{c3}	0.5	0.035	1	0.07
	S_{c4}	0.5	0.035	1	0.07
	S_{c5}	0.5	0.035	1	0.07

Table 2. Comparison of suction velocity to upstream velocity, $U_0 = 16.7$ m/s

U_0 (m/s)	S_c	U_{Sc1} (m/s)	$\frac{U_0}{U_{Sc1}}$	U_{Sc2} (m/s)	$\frac{U_0}{U_{Sc2}}$
16.7	S_{c1}	0.5	0.03	1	0.06
	S_{c2}	0.5	0.03	1	0.06
	S_{c3}	0.5	0.03	1	0.06
	S_{c4}	0.5	0.03	1	0.06
	S_{c5}	0.5	0.03	1	0.06

Table 3. Comparison of suction velocity to upstream velocity, $U_0 = 19.4$ m/s

U_0 (m/s)	S_c	U_{Sc1} (m/s)	$\frac{U_0}{U_{Sc1}}$	U_{Sc2} (m/s)	$\frac{U_0}{U_{Sc2}}$
19.4	S_{c1}	0.5	0.025	1	0.05
	S_{c2}	0.5	0.025	1	0.05
	S_{c3}	0.5	0.025	1	0.05
	S_{c4}	0.5	0.025	1	0.05
	S_{c5}	0.5	0.025	1	0.05

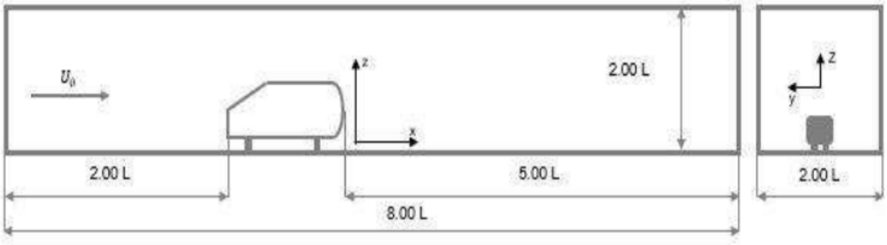


Fig. 2 Computational Domain

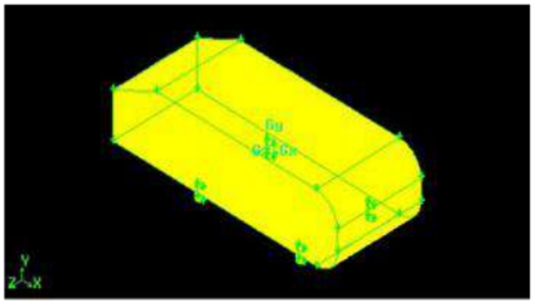


Fig. 3 Display of test model's grid

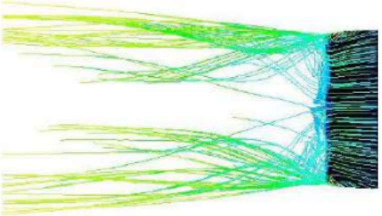
The method of calculating the aerodynamic drag of the model is shown in the relation of the drag coefficient with the drag force [15]:

$$Cd = \frac{Fd}{\frac{1}{2}\rho V^2 L^2}$$

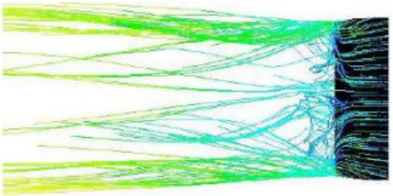
3. Results and Discussion

3.1. Flow Field

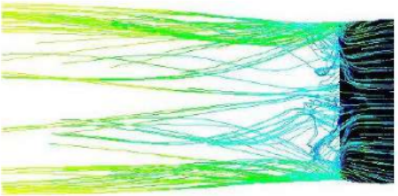
Comparison of flow fields obtained through a computational approach to models without flow control and using flow control with velocities of 0.5 m/s and 1 m/s for each level of upstream velocity is shown in Fig. 4, 5 and 6.



a. Without active control

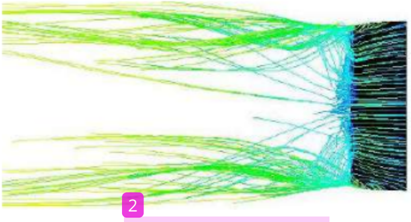


b. With active control by suction, $U_{Sc1} = 0.5$ m/s

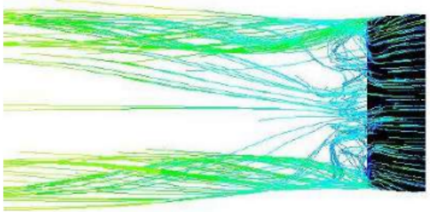


c. With active control by suction, U_{Sc2} = 1 m/s

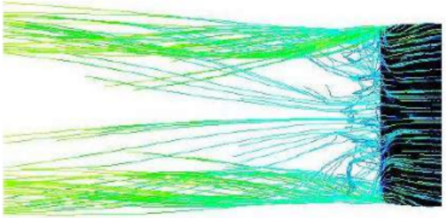
Fig. 4 Velocity pathlines with upstream velocity, U_0 = 13.9 m/s



a. Without control

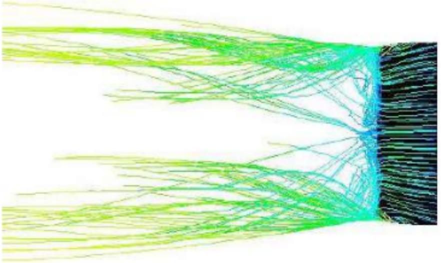


b. With active control by suction, U_{Sc1} = 0.5 m/s

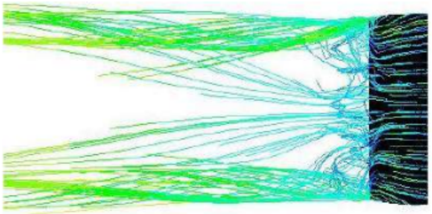


c. With active control by suction, U_{Sc2} = 1 m/s

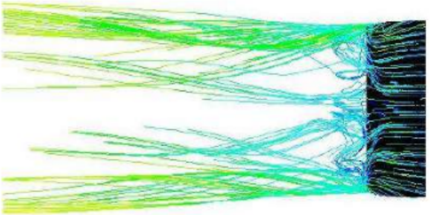
Fig. 5 Velocity pathlines with upstream velocity, U_0 = 16.7 m/s



a. Without active control



b. With active control by suction, $U_{Sc1} = 0.5$ m/s



c. With active control by suction, $U_{Sc2} = 1$ m/s

Fig. 6 Velocity pathlines with upstream velocity, $U_0 = 19.4$ m/s

The velocity pathlines shown in Fig. 4, 5 and 6, indicate the formation of the wake that occurs in models without active control and using active control. At the upstream velocity of 13.9 m/s, the velocity pathline of the model without control shows that the wake phenomenon is quite large due to the flow separation that occurs at the back of the model. The flow that moves regularly will split and form a wake that causes drag force and affects vehicle performance [16]. For models that have active controls with a suction velocity of 0.5 m/s, it appears that the formation of wake tends to be smaller and there is a delay in flow separation when compared to models without active control. Likewise, the model with a suction velocity of 1 m/s also shows that wake formation tends to be smaller but not smaller when compared to models with a suction velocity of 0.5 m/s. At the upstream velocity of 16.7 m/s indicates that the largest build formation occurs in models without active control. For models with a suction velocity of 0.5 m/s, results indicates a reduction in the wake area caused by a delay in flow separation. Reduction of the wake area due to the separation delay also occurs in the model with a suction speed of 1 m/s but the reduction is not as big as the model with a suction speed of 0.5 m/s. At the upstream speed of 19.4 m/s, for without control model shows that the wake phenomenon is quite large. Wake area reduction is obtained in models with active control where 0.5 m/s suction velocity gives the greatest reduction compared to models without active control and models with a suction velocity of 1 m/s. This indicates that the use of active suction control can minimize wake formation so that aerodynamic drag reduction occurs. The same thing was expressed by Harinaldi et al, where the reduced wake would affect reducing drag aerodynamics by 13.86% [17]. Wake structure, other than caused by flow separation is also influenced by the presence of longitudinal vortices that appear at the edges of the side, rear side of the test model. Longitudinal vortex is formed due to the flow velocity difference between the wake and the side area of the test model [18].

3.2. Drag Coefficient

The drag coefficients of the model without active control and models that are equipped with active control by suction are shown in Tables 4, 5 and 6.

Table 4. Drag coefficient without active control

U_0 (m/s)	Fd (N)	Cd
13.9	0.373	1.502
16.7	0.526	1.469
19.4	0.701	1.449

Table 5. Drag coefficient with active control by suction, $U_{Sc1} = 0.5$ m/s

U_0 (m/s)	Fd (N)	Cd
13.9	0.340	1.371
16.7	0.474	1.324
19.4	0.652	1.292

Table 6. Drag coefficient with active control by suction, $U_{Sc2} = 1$ m/s

U_0 (m/s)	Fd (N)	Cd
13.9	0.341	1.372
16.7	0.467	1.327
19.4	0.628	1.298

Tables 4, 5 and 6 show reduction in the drag coefficient along with an increase in upstream velocity on all test models. This is because the higher the velocity of fluid flow, the value of the pressure coefficient on the back of the model will be higher so that aerodynamic drag is lower. This is also proved by the Wessen & Thiele study in which the use of active controls can increase the average pressure distribution thereby reducing aerodynamics drag [10]. For models without active control, the drag coefficient at each upstream speed 13.9 m/s, 16.7 m/s and 19.4 m/s respectively 1.502, 1.469 and 1.449. For models with a suction velocity of 0.5, the drag coefficient for each velocity is 1.371 for 13.9 m/s, 1.324 for 16.7 m/s and 1.292 for upstream velocity of 19.4 m/s. In the model with a suction velocity of 1 m/s, the drag coefficient for the upstream velocity of 13.9 m/s is 1.372, 16.7 m/s for 1.327 and 1.298 for the upstream velocity of 19.4 m/s.

The comparison of the drag coefficient reduction values of the model without active control and the models that are equipped with active suction control are shown in Table 7. On the other hand, the relationship of drag coefficient and upstream velocity is presented in Fig. 7. Table 7 and Fig. 7 show the upstream velocity of 13.9 m/s aerodynamic drag reduction for a suction velocity of 0.5 m/s is 8.713% and 8.703% for a suction velocity of 1 m/s. At an upstream velocity of 16.7 m/s, the drag reduction for a suction velocity of 0.5 m/s and 1 m/s were 9,846 and 9,646, respectively. At an upstream velocity of 19.4 m/s is the largest drag reduction where for a suction velocity of 0.5 m/s is

10.9% and for 1 m/s is 10.46%. These results indicate that the largest aerodynamic drag reduction is obtained on models with a suction velocity of 0.5 m/s with an upstream velocity of 19.4 m/s. A similar research was carried out by Lehugeur & Gillieron where the actuation of active flow control in the form of suction had a positive impact on reducing aerodynamic drag [8].

Table 7. Comparison of drag coefficient

U_0 (m/s)	Cd		
	Without active control	U_{Sc1} = 0.5 m/s	U_{Sc2} = 1 m/s
13.9	1.5022	1.3714	1.3715
Reduction (%)		8.713	8.703
16.7	1.4687	1.3241	1.3270
Reduction (%)		9.846	9.646
19.4	1.4499	1.2919	1.2982
Reduction (%)		10.9	10.46

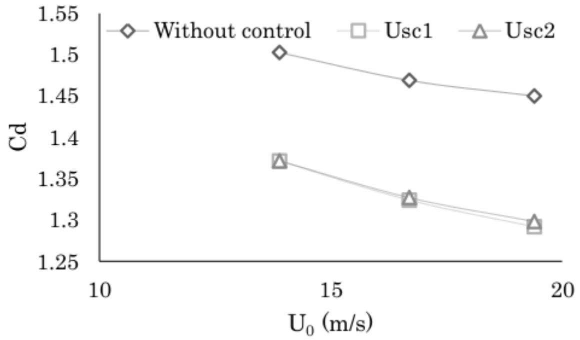


Fig. 7 Relationship of drag coefficient and upstream velocity.

4. Conclusion

Based on the results of the study, it can be concluded as follows:

1. The use of active control by suction influences wakes formation due to flow separation, where the smallest wake phenomenon is obtained in models with active control at a suction speed of 0.5 m/s.
2. The application of active control by suction affects aerodynamic drag, where the greatest drag reduction occurred with the values of 10.9% for the test model with a suction speed of 0.5 m/s.

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