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Numerical Study of The Effects of Vehicle Arrangement on Aerodynamics Resistance

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ABSTRACT

The cause of drag force vehicle accounts high fuel losses. Fuel consumption is adversely affected due to aerodynamic forces, which specially is the drag force. Vehicles that are moving in certain arrangement allows for a significant decrease in fuel consumption at highway speeds by reducing the aerodynamic drag on the moving vehicles. In this paper, the effect of vehicle arrangement on the aerodynamic resistance was numerically investigated. The vehicle models were arranged back-to-back with difference distances between each other. The distance was varied with 1.5 m, 2.0 m and 2.5 m. Computational Fluid Dynamics (CFD) was performed using ANSYS-Fluent software. The results in terms of drag coefficient were obtained for each of distance setting. There are nine different arrangements were studied. It was found out that the lowest average drag force of which 0.1857 experienced by vehicle model that are arranged at the distance of 1.5m and 2.5 m. This average drag coefficient shows a reduction of 26.8%. Consequently, the aerodynamics resistance can be significantly reduced by having a proper arrangement of vehicle cruising in highways.

1. Introduction

Aerodynamic resistances comprise of about 80% of drag force that can significantly affect the vehicle fuel consumption [1,2]. This resistance becomes larger when the vehicle moves faster [3-5]. Meanwhile, the stringent emission requirement from the European Union imposed on vehicle manufacturers in effort to reduce air and noise pollution have sparked flourishing research progress in the field. Significant progress has been made on examining the effect of vehicle arrangement on aerodynamic drag. Since drag is one of the determining factors in aerodynamic performance, various lead-ing or positioning and vehicle body configuration offer increased efficiency. Prominent examples of such configuration is cycling platoon where riders in at the tail end of platoon have drag of approximately 10% of what isolated rider is experiencing [6]. The concept of reducing road vehicle drag by harnessing the aerodynamic interference between closely spaced vehicles has acquired

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considerable attention in recent years due to the growing capabilities of vehicle autonomy and artificial intelligence [7].

Meanwhile, the use of Computational Fluid Dynamics (CFD) in determining vehicle aerodynamics performance has been increasing over the years owing to the advancement in the hardware [8-10].

Platooning in truck transportation has been seen to getting significant attention from researchers especially in autonomous vehicle control system. In truck platooning form, several trucks are digitally connected and steered by intelligent driving support system or better known as autonomous driving system. The cruising speed is computerized controlled which includes lane assist, and automated braking. [11,12]. Fernandes and Nunes [11] show that by platooning autonomous vehicles which are moving in controlled environment, the drag force can be significantly reduced. Since the inter-vehicle distance is reduced, the rear vehicle that is following the lead vehicle can enter into the wake area of the front vehicle. As such, the interacted flow fields between two adjacent vehicles can potentially bring down the drag force [13,14]. In this paper, the effect of vehicle arrangement on the aerodynamic resistance is numerically investigated. Nine different set of distance were fixed and numerical simulations were performed to obtain the coefficient of drag. The main objective of this research is to investigate the best aerodynamic performances with different combination of distance between bodies. As such, the results can be utilized to manage the platooning transportation in autonomous trucks.

2. Research Methodology

2.1 Numerical Domain

In this project, Ahmed model [15] are utilized as for the numerical domain. Figure 1 shows the model dimension utilized for the numerical domain.

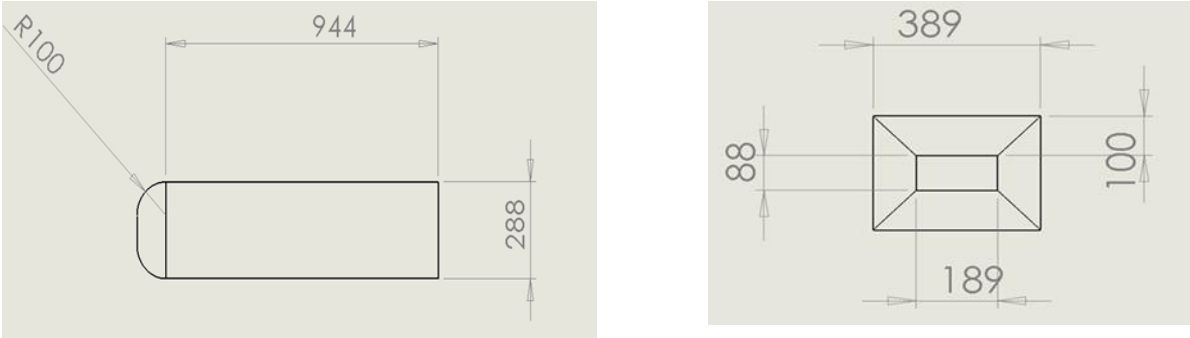

Fig. 1. Dimensions of the Ahmed body utilized for the domain

The geometrical domain was created using Design Modeler in ANSYS Fluent software. Then the model is arranged in such position which is defined as platoon arrangement as shown in Figure 2**.**

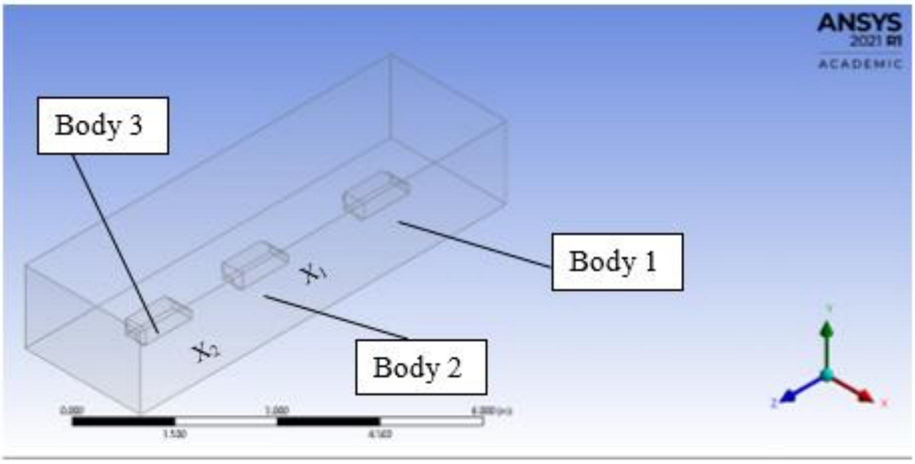

Fig. 2. Vehicle in platoon arrangement

2.2 Governing Equations

The governing equations utilized for the numerical model are the typical fluid motion combined with reacting flows. The mass conservation equation (continuity) is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u_x) + \frac{\partial}{\partial y}(\rho u_y) + \frac{\partial}{\partial z}(\rho u_z) = S_m \tag{1}$$

where S_m is the source term. An example of this term is vaporization of liquid or any user-defined source. Nevertheless, in this numerical model the value of S_m is fixed to 0. For a steady state condition, $\frac{\partial \rho}{\partial t} = 0$. The momentum conservation equation in x-direction

$$\begin{aligned}\frac{\partial \rho u_x}{\partial t} + \frac{\partial(\rho u_x u_x)}{\partial x} + \frac{\partial(\rho u_y u_x)}{\partial y} + \frac{\partial(\rho u_z u_x)}{\partial z} \\ = -\frac{\partial p}{\partial x} - \frac{\partial}{\partial x}\left(\frac{2}{3}\mu(\nabla \cdot \vec{u}) + 2\mu \frac{\partial u_x}{\partial x}\right) + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right)\right] \\ + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right)\right] + \rho f_x\end{aligned} \tag{2}$$

Momentum equation in y-direction

$$\begin{aligned}\frac{\partial(\rho u_x u_y)}{\partial x} + \frac{\partial(\rho u_y u_y)}{\partial y} + \frac{\partial(\rho u_z u_y)}{\partial z} \\ = -\frac{\partial p}{\partial y} - \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right)\right] + \frac{\partial}{\partial y}\left(\frac{2}{3}\mu(\nabla \cdot \vec{u}) + 2\mu \frac{\partial u_y}{\partial y}\right) + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u_z}{\partial y} + \frac{\partial u_y}{\partial z}\right)\right] \\ + \rho f_y\end{aligned} \tag{3}$$

Momentum equation in z-direction

$$\frac{\partial(\rho u_x u_z)}{\partial x}+\frac{\partial(\rho u_y u_z)}{\partial y}+\frac{\partial(\rho u_z u_z)}{\partial z} = -\frac{\partial p}{\partial z}-\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u_x}{\partial z}+\frac{\partial u_z}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u_z}{\partial y}+\frac{\partial u_y}{\partial z}\right)\right]+\frac{\partial}{\partial z}\left(\frac{2}{3}\mu(\nabla\cdot\vec{u})+2\mu\frac{\partial u_y}{\partial z}\right) + \rho f_z \tag{4}$$

3. Results and Discussion

There are nine (9) cases presented in the table. For each of case, the distance between Body 1 and Body 2 (X_1) and the distance between Body 2 and Body 3 (X_2) is varied. For example, in Case 1, the value of X_1 and X_2 is fixed to 1.5 m respectively and the governing equation is solved using Fluent 6.3 software. The results in terms of coefficient drag for each of body are calculated and presented in Table 1. Meanwhile, Figure 3 shows one of the velocity patterns for Case 2. On average, the drag coefficient for the intermediate body which is in this case is Body 2 is lower than the leader body (Body 1). This pattern is in line with previous results obtained from Song *et al.,* [16]. Generally, from the results shown in the Table 1, it can be concluded that in Case 3, the coefficient of drag is the lowest as compared to other 8 cases. It has been proven previously that platoon vehicle arrangement can decrease carbon emission and fuel consumption. In aerodynamics theory, when vehicles are cruising in platoon arrangement, the vehicle in front is affected by the air pressure that occurs by the pushing force of vehicle behind it. The vehicle close behind another vehicle is less affected by the aerodynamic drag due to the vehicle in front of it breaking the strong wind.

Since aerodynamic resistance significantly affect the fuel consumption of a vehicle, the aerodynamics enhancement that is achieved by properly arrange these vehicles can help to reduce the operational expense and also the more environmentally friendly.

Table 1
Drag Coefficient for each case of arrangement

Case	Distance between Body 1 & 2 X_1 (m)	Distance between Body 2 & 3 X_2 (m)	Drag Coefficient (C_d) Body 1	Body 2	Body 3
1	1.5	1.5	0.2296	0.2266	0.3352
2	1.5	2.0	0.2187	0.2986	0.2857
3	1.5	2.5	0.1472	0.1857	0.2177
4	2.0	1.5	0.2693	0.2143	0.3345
5	2.0	2.0	0.2647	0.2721	0.3039
6	2.0	2.5	0.1881	0.2053	0.1817
7	2.5	1.5	0.3191	0.2180	0.2850
8	2.5	2.0	0.3149	0.2838	0.2802
9	2.5	2.5	0.3351	0.2889	0.3394
Average			0.2540	0.2437	0.2848

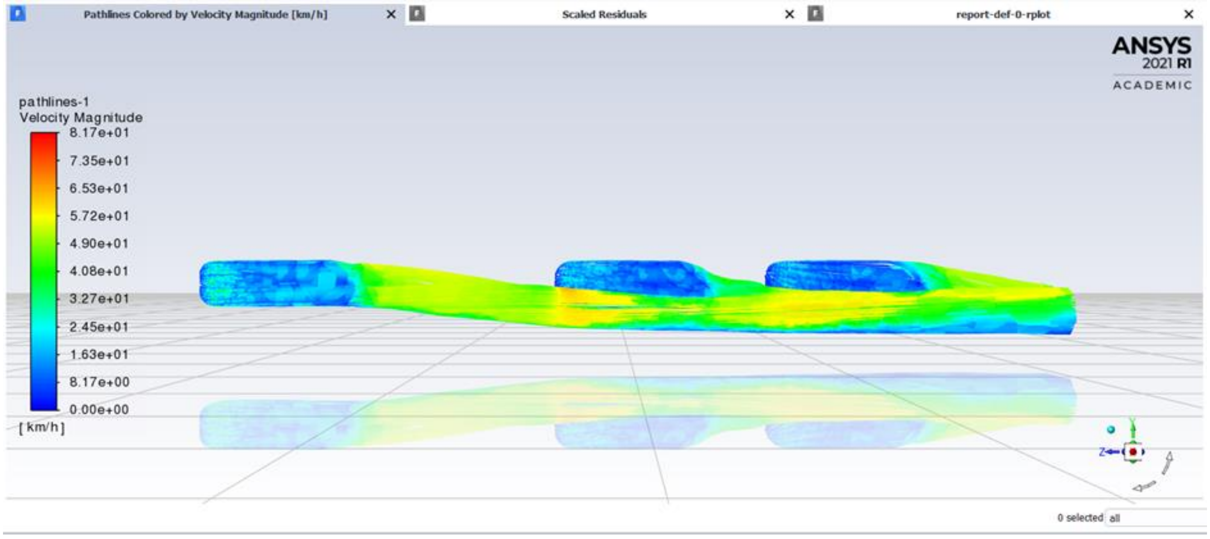

Fig. 3. Velocity Streamline Pattern for Case 2

4. Conclusions

It can be concluded where the lowest drag force experienced by the all bodies are for Case 3, where the distance between Body 1 and 2 (X_1) is 1.5 m and the distance between Body 2 and Body 3 (X_2) is 2.5 m. Therefore, it can be said proper arrangement of vehicle moving at cruising speed on highways can significantly reduce the aerodynamic resistance. Consequently, fuel consumption can be significantly reduced.

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References

[1] Le Good, Geoff, Max Resnick, Peter Boardman, and Brian Clough. "Effects on the aerodynamic characteristics of vehicles in longitudinal proximity due to changes in style." *SAE Technical Paper* (2018): 37-55.

[2] Haffner, Yann, Ruiying Li, Marcello Meldi, and Jacques Borée. "Drag reduction of a square-back bluff body under constant cross-wind conditions using asymmetric shear layer forcing." *International Journal of Heat and Fluid Flow* 96 (2022): 109003. https://doi.org/10.1016/j.ijheatfluidflow.2022.109003

[3] Piechna, Janusz. "A Review of Active Aerodynamic Systems for Road Vehicles." *Energies* 14, no. 23 (2021): 7887. https://doi.org/10.3390/en14237887

[4] Watkins, Simon, and Gioacchino Vino. "The effect of vehicle spacing on the aerodynamics of a representative car shape." *Journal of wind engineering and industrial aerodynamics* 96, no. 6-7 (2008): 1232-1239. https://doi.org/10.1016/j.jweia.2007.06.042

[5] Abobaker, Mostafa, Sogair Addeep, Lukmon O. Afolabi, and Abdulhafid M. Elfaghi. "Effect of Mesh Type on Numerical Computation of Aerodynamic Coefficients of NACA 0012 Airfoil." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 87, no. 3 (2021): 31-39. https://doi.org/10.37934/arfmts.87.3.3139

[6] Blocken, Bert, Thijs van Druenen, Yasin Toparlar, Fabio Malizia, Paul Mannion, Thomas Andrianne, Thierry Marchal, Geert-Jan Maas, and Jan Diepens. "Aerodynamic drag in cycling pelotons: New insights by CFD simulation and wind tunnel testing." *Journal of Wind Engineering and Industrial Aerodynamics* 179 (2018): 319-337. https://doi.org/10.1016/j.jweia.2018.06.011

[7] Ebrahim, Hesham, and Robert Dominy. "Wake and surface pressure analysis of vehicles in platoon." *Journal of Wind Engineering and Industrial Aerodynamics* 201 (2020): 104144. https://doi.org/10.1016/j.jweia.2020.104144

[8] Bajuri, Muhammad Nur Arham, Djamal Hissein Didane, Mahamat Issa Boukhari, and Bukhari Manshoor. "Computational Fluid Dynamics (CFD) Analysis of Different Sizes of Savonius Rotor Wind Turbine." *Journal of Advanced Research in Applied Mechanics* 94, no. 1 (2022): 7-12.

[9] Jena, Siddharth, and Ajay Gairola. "Novel Boundary Conditions for Investigation of Environmental Wind Profile Induced due to Raised Terrains and Their Influence on Pedestrian Winds." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 27, no. 1 (2022): 77-85. https://doi.org/10.37934/araset.27.1.7785

[10] Akaje, Wasiu, and B. I. Olajuwon. "Impacts of Nonlinear thermal radiation on a stagnation point of an aligned MHD Casson nanofluid flow with Thompson and Troian slip boundary condition." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 6, no. 1 (2021): 1-15.

[11] Fernandes, Pedro, and Urbano Nunes. "Platooning of autonomous vehicles with intervehicle communications in SUMO traffic simulator." In *13th International IEEE Conference on Intelligent Transportation Systems*, pp. 1313-1318. IEEE, 2010.. https://doi.org/10.1109/ITSC.2010.5625277

[12] Martínez-Díaz, Margarita, Christelle Al-Haddad, Francesc Soriguera, and Constantinos Antoniou. "Platooning of connected automated vehicles on freeways: a bird’s eye view." *Transportation research procedia* 58 (2021): 479-486. https://doi.org/10.1016/j.trpro.2021.11.064

[13] Lee, Woo Jin, Sung Il Kwag, and Young Dae Ko. "The optimal eco-friendly platoon formation strategy for a heterogeneous fleet of vehicles." *Transportation Research Part D: Transport and Environment* 90 (2021): 102664. https://doi.org/10.1016/j.trd.2020.102664

[14] Kalvin, Roman, Juntakan Taweekun, Muhammad Waqas Mustafa, and Saba Arif. "Aerodynamics Analysis and Range Enhancement Study of 81mm Mortar Shell (French Design)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 84, no. 1 (2021): 148-159. https://doi.org/10.37934/arfmts.84.1.148159

[15] Ahmed, Syed R., G. Ramm, and Gunter Faltin. "Some salient features of the time-averaged ground vehicle wake." *SAE Transactions* (1984): 473-503. https://doi.org/10.4271/840300

[16] Song, Mingtao, Feng Chen, and Xiaoxiang Ma. "Organization of autonomous truck platoon considering energy saving and pavement fatigue." *Transportation Research Part D: Transport and Environment* 90 (2021): 102667. https://doi.org/10.1016/j.trd.2020.102667