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Numerical Investigation of the Aerodynamic Drag Using a Backstep on Ahmed Body Model

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ABSTRACT

The Aerodynamic drag has a great impact on the fuel consumption of road vehicles, which affects directly the economy and the environment. Controlling the flow around bluff bodies using passive techniques has efficient results in reducing the aerodynamic drag, especially the pressure drag. This paper presents a numerical study of a passive flow control technique used on the simplified Ahmed body model with 25° slant angle. The passive flow control performed is a backstep used at the rear base of the model. This study was conducted using ANSYS Fluent as Computational Fluid Dynamics (CFD) software to simulate the flow around the model. The backstep case have shown promising results and an impact on the pressure drag reduction.

Key words: Aerodynamic drag, Passive flow control, ANSYS Fluent, CFD and Ahmed Body.

INTRODUCTION

The depletion of fossil fuels, the increase of oil prices and the climate change concern enhanced the importance of reducing the fuel consumption. Aerodynamic drag and Vehicle weight are recognized as the main sources of fuel consumption (MUKUT & ABEDIN 2019). According to conducted research (SUDIN 2014), the aerodynamic drag of road vehicles by itself contributes to up to 50 percent of the fuel consumed in highway speeds. More specifically, aerodynamic drag increases with the square of the vehicle velocity (LEE, 2018). The

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aerodynamic drag of ground vehicles is mainly pressure drag and skin friction drag. A thorough analysis concerning the aerodynamic drag for ground transportation have shown that pressure drag represents 80% of the overall aerodynamic drag, while the skin friction drag represents 20% (WOOD, 2004). Therefore, it is strongly suggested to primarily focus on pressure drag in the future drag reduction research. It is also suggested to study the drag at the rear part of the vehicles geometry as it contributes to more than 40% of the pressure drag (CHOI 2008). The pressure drag is created from the difference of pressure between the front and the rear parts of the vehicle, and the wake area is the main cause of the low pressure behind the vehicle.

The flow control is a mechanism that was introduced to modify the flow structure around the bodies to prevent or delay the flow separation. Flow Control is divided into two types; active methods and passive ones. The active methods require energy expenditures and usually involve sophisticated control feedback systems, and the passive control techniques don't involve any energy input and they are easy to implement, cheap and works for a wide scope of conditions.

Altaf et al. (ALTAF 2014) have numerically studied an elliptically shaped flap as a passive add-on device to MAN TGX truck and compared it to rectangular flaps. A maximum of 11% drag reduction was obtained for elliptical flap in comparison to 6.37% for the rectangular one.

Tian et al. (TIAN et al. 2017) carried out a numerical study of two types of flaps added to two different Ahmed body models; 25°and 35° slant angles. They analyzed the effect of a large and small flaps on the aerodynamic drag. They demonstrated that both types of flaps are more efficient on the 25° Ahmed model than the 35° model. The best results obtained were a 21.2% drag reduction with a large flap placed on the slant side edge and a 17.9% reduction for both flap types placed on the top edge. It was demonstrated that weakening the longitudinal vortex at the slant side edge is the key to reduce the aerodynamic drag.

Sadeghipour et al. (SADEGHIPOUR 2020) studied the bluff bodies encased in porous media and its contribution in passive flow control. Lorite-Diez et al. (LORITE-DÍEZ 2020) investigated the case of rear cavities implemented to a square back Ahmed Body and they have experimentally evaluated their effect for different yaw angles less than 10 degree. The aerodynamic drag can be reduced up to 10% for a curved cavity. More studies can be conducted to study the effect of Reynolds number on the performance of curved cavities as well as investigate its performance while implemented in a real truck model.

This paper covers a numerical study of aerodynamic drag reduction using a backstep at the rear end of Ahmed Body model. The study first was carried for 2D Ahmed body after that extended to 3D. This passive technique was adapted to weaken the vortex shedding at the base of the body and increase the pressure to reduce the pressure drag.

MODEL SETUP

For the numerical simulation, the model used is Ahmed body model introduced by Ahmed *et al.* (Ahmed 1984) as it is a model that represents the essential aerodynamic flow features over bluff bodies and it mimics the different types of the road vehicles. For this study, first the two-dimensional model is used with a rear slant angle of φ=25° and the dimensions are presented in the figure 1.

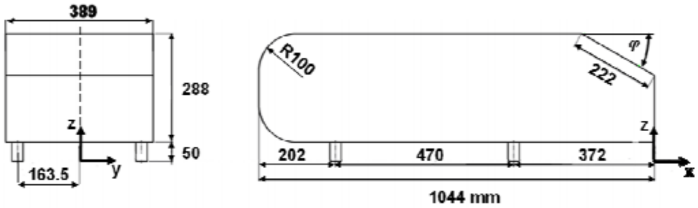

Figure 1: schematic view of Ahmed Body model **(HINTERBERGER 2004)**

The two-dimensional Ahmed Body was modeled and simulated using ANSYS-FLUENT to validate the numerical results with the experimental data given by Ahmed et al. **(Ahmed 1984)**. The mesh parameters are given in table 1. The simulation was carried out using the K-epsilon turbulence model, the velocity was set to 40 m/s, and different solution methods were used. The third-order MUSCL was the best solution method to validate the results and it is used for the other simulations. The simulations were carried until convergence.

Property	**Parameter**
Max. number of inflation layers	10
Edge sizing	0.005
First layer thickness	0.00075
Minimum cell size	0.002
Surface growth rate	1.2
Total no. of cells	23 610

Table 1: Mesh parameters

RESULTS

The results obtained from the 2D baseline simulation are presented in table 2. The CFD model is validated and will be used for further simulations adding the backstep to the Ahmed Body model.

Experimental (Ahmed 1984)	**Numerical**	**ERROR**
0.28	0.301	7.50%

Table 2: Obtained results

Figure 2: Pressure contour

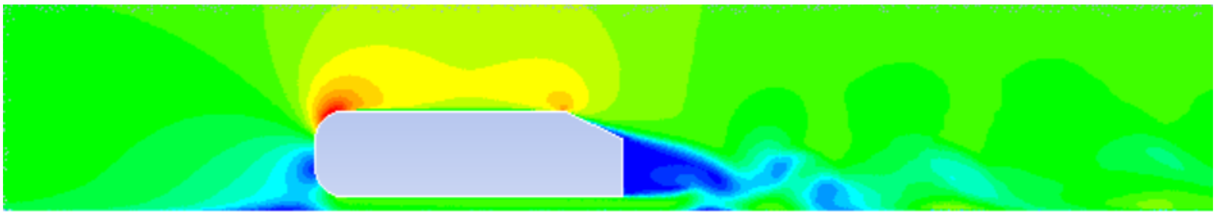

Figure 3: Velocity contour

Figures 2 and 3 present pressure and velocity contours of the flow over the 2D Ahmed body model, where the vortex shedding is shown clearly behind the body.

The area behind the model knows a drop of pressure which causes the pressure drag. The goal of this study is to implement a backstep at the rear end of the body to create opposite vortices that will cancel some of the vortices behind the vehicle. This will lead to weakening the vortex shedding and increase the pressure behind, and therefore the pressure drag can be reduced.

The backward step is a shape modification applied to the studied model. It is a cavity added to the bottom side of the rear part of the body. The Backstep parameters are the height h and the width w as shown in Figure 4. Different configurations of the backstep were investigated with variation of the h and w. The height H of the body was used as a reference and the parameters were chosen as a combination of 0.10H, 0.15H, 0.20H and 0.25H.

Figure 4: The backstep used on the Model

The numerical results obtained for the different parameters of the backward step are presented in Tables 3, 4, 5 and 6.

	h/H			
	0.10	**0.15**	**0.20**	**0.25**
BASELINE	0.301	0.301	0.301	0.301
Cd	0.313	0.31	0.308	0.307
Difference	3.99%	2.99%	2.33%	1.99%

Table 3: Results for w = 0.10H

	h/H			
	0.10	**0.15**	**0.20**	**0.25**
BASELINE	0.301	0.301	0.301	0.301
Cd	0.289	0.294	0.29	0.287
Difference	-3.99%	-2.33%	-3.65%	-4.65%

Table 4: Results for w = 0.15H

	h/H			
	0.10	**0.15**	**0.20**	**0.25**
BASELINE	0.301	0.301	0.301	0.301
Cd	0.309	0.305	0.287	0.304
Difference	2.66%	1.33%	-4.65%	1.00%

Table 5: Results for w = 0.20H

	h/H			
	0.10	**0.15**	**0.20**	**0.25**
BASELINE	0.301	0.301	0.301	0.301
Cd	0.305	0.302	0.299	0.3
Difference	1.33%	0.33%	-0.66%	-0.33%

Table 6: Results for w = 0.25H

From the results presented in the tables, we can notice that the backward step does not imply a drag reduction for all the dimensions presented. For instance, with the width 0.10H the drag has been increasing for the different values of the step height. The best configurations regarding the drag reduction are with a step width of 0.15H. The drag reduction was achieved for all height values, and it was reduced up to 4.65% for the step height 0.25H. The aerodynamic drag reduction achieved in some of these cases explains that the backstep have an impact on the flow over the body and can be considered for more studies.

The two-dimensional investigation can be limited as the flow and the vortex generation are fully three-dimensional. The three-dimensional case of the combinations that have shown the largest drag reduction, which are the ones with a width 0.15H, is presented in Table 7.

	h/H			
	0.1	**0.15**	**0.20**	**0.25**
BASELINE	0.289	0.289	0.289	0.289
Cd	0.281	0.285	0.285	0.288
Difference	-2.77%	-1.38%	-1.38%	-0.35%

Table 7: Results of the three-dimensional case of a backstep with w = 0.15H

The results obtained shows that the drag reduction is maintained in the three-dimensional case. The amount of drag reduction is slightly lower than the one obtained in the two-dimensional study, and it can be explained by the complexity of the three-dimensional flow over bluff bodies. The reduction of the aerodynamic drag can be improved by rounding the corners of the backward step and interesting results can be achieved.

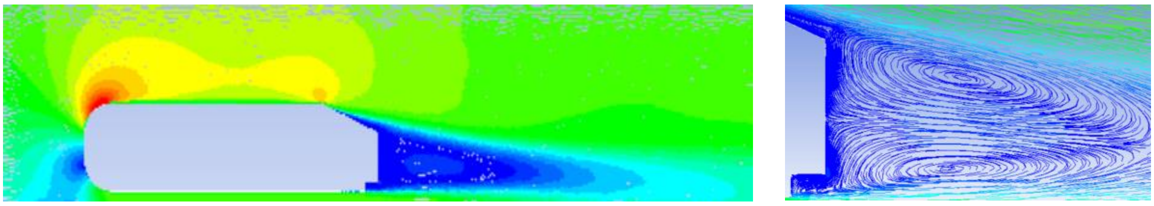

Figure 5: Velocity streamlines

Figure 5 illustrates the velocity streamline around the Ahmed body model. The wake area is represented by the blue streamlines, and it is shown in the figure the small vortices created in the step area which have affected the pressure drag.

CONCLUSION

The current investigation is a study of the backward step used at the rear end of the Ahmed body model, and different step parameters were examined. For 2D case, the modification has shown a drag reduction up to 4% for some specific dimensions. The best backward step configuration was used in a three-dimensional model, and a drag reduction was achieved. The backstep is a simple modification, however it has interesting results. The three-dimensional case can be more studied for different step dimensions and adjustment of the sharp corners.

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