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COMPUTATIONAL INVESTIGATION OF DRAG REDUCTION ON AN AHMED BODY USING SQUARE GROOVES

Rawail Haseem
Department of Thermal Energy Engineering
National University of Sciences and Technology,
NUST
H-12 Main Campus, Islamabad
rawail_haseem@hotmail.com

Adeel Javed
Department of Thermal Energy Engineering
National University of Sciences and Technology,
NUST
H-12 Main Campus, Islamabad
adeeljaved@uspcase.nust.edu.pk

Abstract

In Pakistan 96% of the freight transportation is done through trucks[1]. This aerodynamic pressure drag causes up to 15-20% extra fuel consumption [2]. Aerodynamic drag can be reduced by using different passive techniques of fluid flow control. In this paper, the influence of square grooves on the passive drag reduction has been evaluated. In the first phase simulations have been performed to investigate the skin friction coefficient of smooth flat plate with square groove in it. These grooves are placed transverse to the incoming flow. This results in increasing the friction drag along the boundary causing the transition of laminar flow to turbulent. Similar technique is used in the second phase around a square back Ahmed Body. The study has been conducted with computational fluid dynamics (CFD) simulations using ANSYS Fluent. Unsteady Reynolds Averaged Navier-Stokes (URANS) formulation has been employed with Transient time and 2 equation k-epsilon realizable model, in the simulation. The focus of this study is to help the transportation sector of Pakistan by making efficient aerodynamic design. This study is applicable to Pakistani heavy transport vehicles with an intention to reduce the high fuel consumption which is caused due to high pressure drag

Keywords: Ahmed Body; CFD; Flat Plate; Square Grooves.

1. INTRODUCTION

1.1 General

The importance of energy conservation has been a driving force behind the ongoing research that will reduce the drag on transport vehicles. Passive control of the flow field around the body may result in aerodynamic drag reduction and a conforming performance enhancement.

Surface roughness has been widely investigated as a means of modifying the turbulent boundary layer. It is assumed that the Transverse Square Grooves create a low-pressure area immediately downstream, which sucks fluid back from the main flow, creating a circulating vortex prolonging the turbulent development in the boundary layer [5], thus controlling the boundary layer separation over the body. In 2-dimensional flow the boundary layer separates at the point in the flow where the shear stress on the wall is almost zero and the flow changes into turbulent [3]. Passive and active maneuvering of the flow field may produce drag reduction which causes increase in the performance.

Not in distant past, friction drag reduction methods have gained popularity in relation to less fuel consumption in aircrafts and submarines. Reduction using riblets have drawn more attention due to their greater potential of reducing drag.

1.2 Flat Plate

Square grooves are comparatively easier to develop than a riblet surface. These 2-dimensional square grooves are placed in transverse to the incoming flow. They are more suitable for any further optimization, and when added together, they can further lessen the skin-friction drag. Refrigeration systems, plate heat exchangers and other engineering equipment's use large grove designs [4]. Whereas bearings, automobiles, breaking system and high-pressure equipment's use microscopic grooves.

Contradictory results have been recorded regarding the effectiveness of square grooves [3]. It has been suggested that transverse square grooves, optimally sized and located, could result in skin-friction drag reduction. [5].

1.3 Ahmed Body

In this study a base line drag value is obtained for a Dumper Truck using a Square Back Ahmed Body in Ansys Fluent and the drag reduction through different modifications in the groove design along the

Dumper Body are compared.

The market does not appreciate frequent launching of new models. New truck model demands more time to design and are not affordable for Pakistani buyers. According to a study conducted in Pakistan, aerodynamic pressure drag leads up to 15-20 % of extra fuel consumption [6]. There is a probability that the aerodynamic drag of Dumper Trucks in developing countries like Pakistan can lead to great profit by reducing the fuel consumption.

The corner of vehicles with square back causes the air fleeting by its body to separate, leading to a massive fall in the pressure that produces a long wake behind the vehicle [7], [8]. The target of this study is to develop control solution to reduce the aerodynamic drag of the vehicle without forcing a change in the original design of the body. The success depends upon controlling the point where the separation along the body occurs. Recirculation area at the rear end of the body can be cut down by installing separation accessories at the back or the front of the body.

Intriguing results were achieved with grooves positioned along the boundary, transverse to the incoming flow [9], [10]. This creates a force along the boundary layer which helps shift the separation point resulting in a decrease in pressure drag and decreasing the aerodynamic drag is another effective solution [7], [11]. Besides, the use of artificial rough surface achieves up to 50% reduction in drag. Turbulent laminar transition can also be rushed by using self-adapting surfaces made of special coating [12], [13]. The flow is naturally turbulent in automobile aerodynamics, thus the impact is very low.

2. METHODOLOGY

In the first phase two different configurations of flat plate are simulated and validated through literature. These 2 different configurations consist of*;* ***1)*** *Flat plat with smooth wall,* ***2)*** *Flat Plate with single square groove.*

In the second phase these configurations of grooves are simulated on an Ahmed Body which is compared to a bluff body such as a heavy transport vehicle [14], [11]. Recirculation zones are created due to the separations occurring along the body, resulting in huge drag coefficient. The objective of this paper is to control or reduce the separation area in the wake. A 2-Dimensional study is performed in which we concentrate on the total pressure gradient that governs the aerodynamic drag of Square Back Ahmed Body, which is a simplified form of Dumper Truck.

The use of Transverse Square grooves is a new possibility that can modify the boundary layer behavior. Here the flow control is achieved by means of Transverse Square groove which are inserted on the surface of the body. These square grooves modify the boundary layer effect as it changes the stress forces [15], [16]. The goal is to show how well positioned transverse grooves and their geometry can modify the wake.

In the following we give various results of different configuration of the flat plate and the flow on square back Ahmed Body. We carefully analyze these results and assess the effect of Square Grooves in the flow around the body.

3. GEOMETRICAL DIMENSION

3.1 Flat Plate

Smooth wall

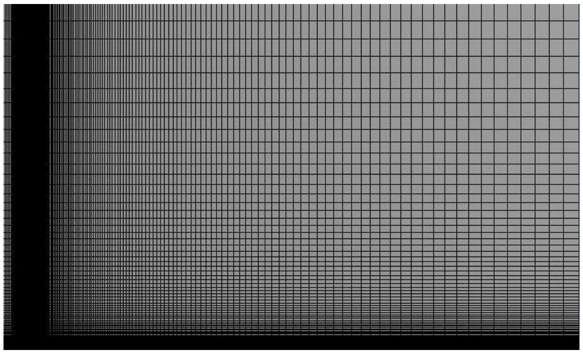


Figure 1 Flat Plate Smooth Wall Mesh

Domain Length	1.75m
Domain Height	1m
Plat Length	1.7m
Inlet Velocity	5.4 mps
Turbulent Intensity	5%
Turbulent Viscosity Ratio	10

Flat Plat with Single Square Groove

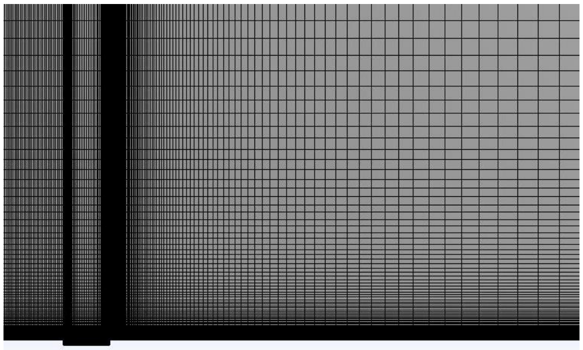


Figure 2 Flat Plate Single Groove Mesh

Domain Length	1.75m
Domain Height	1m
Plat Length	1.7m
Groove Depth	0.014m
Groove Length	0.14m
Inlet Velocity	5.4 mps
Turbulent Intensity	5%
Turbulent Viscosity Ratio	10

3.2 Ahmed Body

Smooth Wall

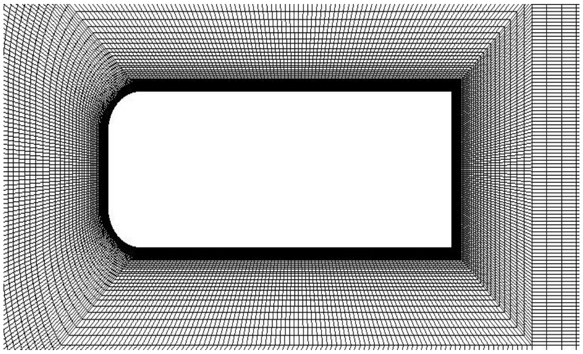


Figure 3 Smooth Wall Ahmed Body Mesh

Domain Length	6.79m
Domain Height	2.33m
Ahmed Body Length	1.044m
Ahmed Body Width	0.39m
Front Filet Raduis	0.10m
Inlet Velocity	5.4 mps
Turbulent Intensity	5%
Turbulent Viscosity Ratio	10

Square Grooves at Rear End

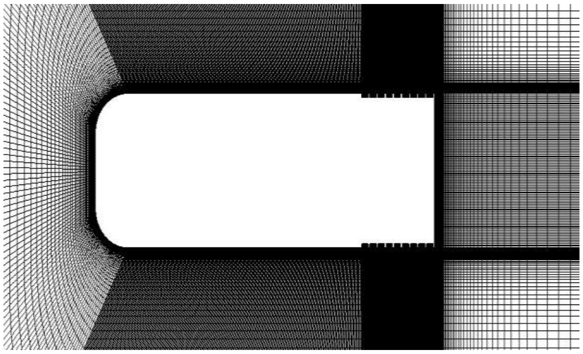


Figure 4 Grooved Wall Ahmed Body Mesh

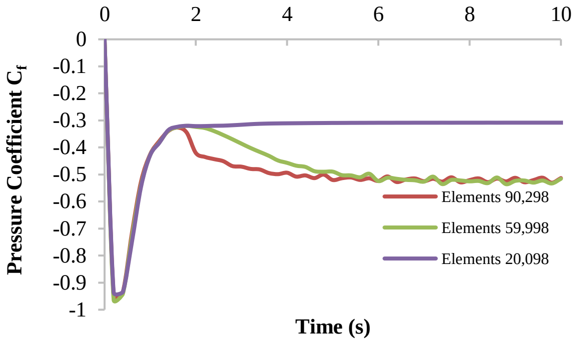
Domain Length	6.79m
Domain Height	2.33m
Ahmed Body Length	1.044m
Ahmed Body Width	0.39m
Front Filet Raduis	0.10m
Groove Depth	0.01m
Groove length	0.02m
Distance between Grooves	0.005m
Inlet Velocity	5.4 mps
Turbulent Intensity	5%
Turbulent Viscosity Ratio	10

4. Grid Independence

Grid independence test is performed to ensure that mesh size does not affect the simulation outcomes. Pressure Coefficient is monitored inside the domain to investigate the convergence history.

Three different mesh are considered by changing the number of nodes along the geometry, resulting in the increase of elements. Number of elements and its effect on Pressure coefficient are discussed below.

Number of Elements	**Pressure Coefficient C_f**
20,098	0.357
59,998	0.545
90,298	0.547



Graph 1 Pressure Coefficient vs Time at Different Number of Elements

Graph 1 shows that the resulting pressure coefficient for elements 59,998 and above is constant but as we decrease the number of elements to 20,098, divergence starts to occur.

5. RESULTS

5.1 Flat Plate

It can be seen from the graph and validated through literature that there is an overshoot just downstream of the groove followed by an undershoot and an oscillatory relaxation back to the smooth- wall value [3].

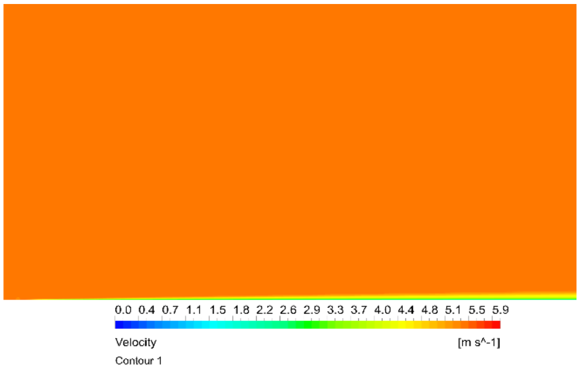
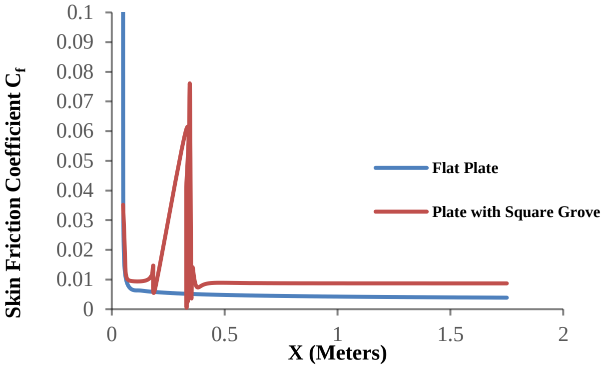


Figure 5 Flat Plate Smooth Wall Velocity Contours



Graph 2 Smooth vs Grooved Wall Skin friction

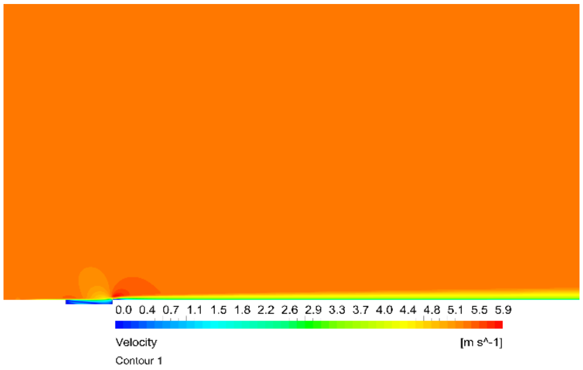


Figure 6 Grooved Flat Plate Velocity Contours

Fig 5 and 6 are the velocity contours of the simulations performed on the Smooth wall Flat Plate and Grooved Wall Flat Plate respectively.

Graph 2 shows the graph between Skin Friction Coefficient and the Length along the flat plate. It is quite visible that there is an abrupt increase in the skin friction coefficient as the incoming flow passes through the Square Groove. This increased skin friction helps in making the flow transition from laminar to turbulent and reduces the length of the separation which helps the flow to stay attached with the body for a longer time, hence reducing the wake.

5.2 *Ahmed Body*

Simulation are performed on an Ahmed Body with a smooth wall and Square Grooves at the rear end of the Ahmed Body.

Firstly, the simulations run on a Smooth Wall Ahmed Body and the Coefficient of Drag was noted. After that Transverse Square Grooves of equal size were created and equally spaced apart at the rear end of the Ahmed Body.

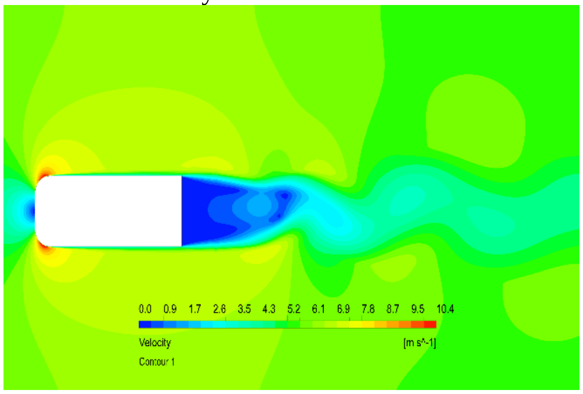


Figure 7 Smooth Wall Ahmed Body Velocity Contour

Fig 7 shows the Velocity contours of the Ahmed Body with Smooth Wall surface. The Blue region behind the body represents the wake created due to the pressure difference between the front and rear end of the body.

After creating Transverse Square Grooves, simulations with the same boundary conditions were run to compare the difference in the wake before and after the grooves were created.

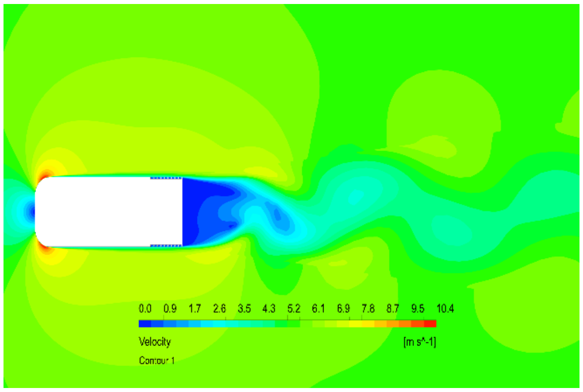
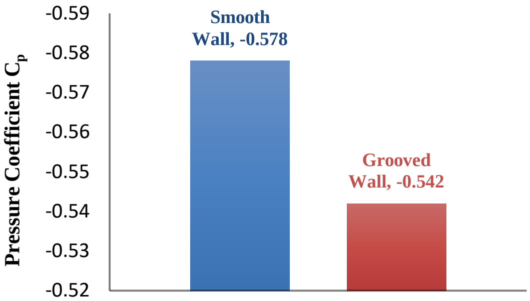


Figure 8 Grooves at the rear end of Ahmed Body Velocity Contour

Fig 8 represents the wake length is decreased due to the creation of grooves at the rear end of the body. Due to limited computational power a minor difference in the wake is captured.



Graph 3 Smooth vs Grooved Wall Coefficient of Pressure

Graph 3 informs us about the mean pressure coefficient taken at a point behind the square back Ahmed Body at (1.2, 0.2, 0) in both domains. The mean pressure coefficient of Smooth wall Ahmed Body jumps from -0.578 to -0.542 of Grooved wall Ahmed Body with an increment of 6.22 %, resulting in the drop of pressure drag.

This difference is made more visually clear by including the streamline in the velocity contours as shown in the Fig 9 and 10.

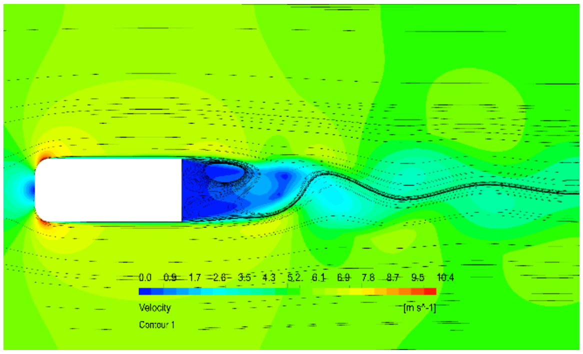


Figure 9 Smooth wall Ahmed Body Streamline Velocity Contour

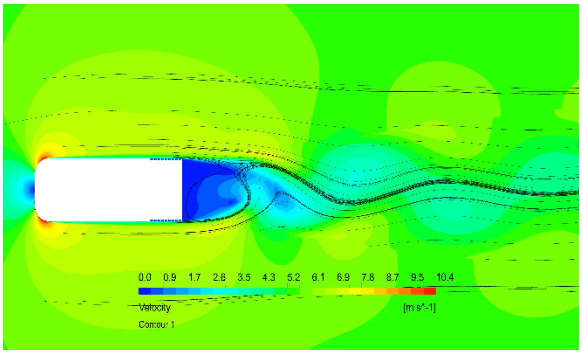


Figure 10 Grooved wall Ahmed Body Streamline Velocity Contour

In the Fig 9 and 10 the streamlines in velocity contours are used to demonstrate the recirculation of flow behind the body, before and after the creation of Transverse Square grooves.

The density of these streamline at the back indicates that the recirculation of the flow at the back of Smooth walled Ahmed body is larger than the Grooved Ahmed Body, hence the wake created on smooth Ahmed body is greater.

REFERENCES

[1] M. A. Choudhary, N. Khan, M. Arshad, and A. Abbas, “Analyzing Pakistan ’ s Freight Transportation Infrastructure Using Porter ’ s Framework and Forecasting Future Freight Demand Using Time Series Models.”

[2] G. Siva and V. Loganathan, “Design and Aerodynamic Analysis of a Car to Improve Performance,” vol. 24, pp. 133–140, 2016.

[3] R. Wahidi and W. Chakroun, “The behavior of the skin-friction coefficient of a turbulent boundary layer flow over a flat plate with differently configured transverse square grooves,” vol. 30, pp. 141–152, 2005.

[4] D. M. Bushnell and J. N. Hefner, Viscous Drag Reduction in Boundary Layers Edited by. .

[5] “The effect of a square groove on a boundary layer.pdf.” .

[6] B. Data and A. Series, “SHORT ROUNDUP ON TRANSPORT INFRASTRUCTURE IN,” 2016.

[7] R. S. Khan and S. Umale, “CFD Aerodynamic Analysis of Ahmed Body,” vol. 18, no. 7, pp. 301–308, 2014.

[8] G. Vehicle, C. Bruneau, and E. Creus, “Analysis of the Active and Passive Drag Reduction Strategies Behind a Square Back Analysis of the Active and Passive Drag Reduction Strategies Behind a Square Back Ground Vehicle,” no. August 2016, 2018.

[9] C. Bruneau, E. Creusé, D. Depeyras, P. Gilliéron, and I. Mortazavi, “Computers & Fluids Coupling active and passive techniques to control the flow past the square back Ahmed body,” Comput. Fluids, vol. 39, no. 10, pp. 1875–1892, 2010.

[10] “Effect of compressibility on the global stability of axisymmetric wake flows,” vol. 660, pp. 499–526, 2010.

[11] “Passive Control Around the Two-Dimensional Square Back Ahmed Body Using Porous,” vol. 130, no. June 2008, pp. 1–12, 2016.

[12] P. W. Bearman and J. K. Harveyt, “Control of Circular Cylinder Flow by the Use of Dimples,” vol. 31, no. 10, pp. 2–5, 1993.

[13] B. Pw, “Investigation of the flow behind a two-dimensional model with a blunt trailing edge and fitted with splitter plates,” vol. 21, pp. 241–255, 1965.

[14] G. Luiz, O. Halila, and S. A. Embraer, “A Numerical Study On Transitional Flows by Means of a Correlation-Based Transition Model,” no. January, pp. 1–34, 2015.

[15] M. J. Walsh, “Riblets as a Viscous Drag Reduction Technique,” vol. 21, no. 4, pp. 1–5, 1983.

[16] W. Engineering and I. Aerodynamics, “Reynolds-number effects in flow around more-or-less bluff bodies,” vol. 89, pp. 1267–1289, 2001.