Reducing Drag of Vehicles with Half-Stepped Cylinder Surfaces Part I: Numerical Optimization

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Introduction

Direct tailpipe emissions account for over 40% of greenhouse gas emissions in California. The state has set goals to reduce greenhouse gas emissions 40% below 1990 levels by 2030 and add five million zero-emission vehicles to California's roads by 2030. Aligned with the California climate action goals, the transportation sector and package delivery services are transitioning their fleets to low-emission and electric vehicles. For a vehicle, the major components of its drag are pressure and viscous drag. Reducing its drag reduces emissions and increases travel range for both gas-powered and electric-powered vehicles.

Study Methods

Parametric studies using computational fluid dynamics have been performed to identify optimized parameters of the half-stepped cylinders for reducing the skin friction of a turbulent boundary layer. The goal of the investigations was to create ridges with half-stepped cylinder rows to control boundary-layer hairpin vortices, relaminarize the turbulent boundary layer, and create microcavities with tandem cylinders to reduce the no-slip boundary conditions and significantly reduce the surface skin-friction coefficient. The studies were performed at a freestream mean velocity of 10 m/s. The flat plate Reynolds number at x = 5 m axial, which corresponds to 0.3 m upstream of the first half-stepped cylinder row, was 2.85 x 106. Figure 1 shows a half-stepped cylinder row with three adjacent cylinders. The parameters changed were the cylinder's diameter and width, the spacing between the adjacent cylinders, and the number of rows. Computational simulations were conducted using the commercial CFD software Ansys Fluent with grids ranging from 1 million to 20 million, depending on the geometry tested. The skin friction coefficient, Cf, was calculated from the wall shear stress. The averaged skin friction coefficient was obtained using the local skin friction coefficients upstream, in between, above, and downstream of the row of cylinders. Results were compared with those for a smooth, flat-plate turbulent boundary layer.

Reducing the skin friction coefficient of the vehicles reduces emissions and improves the travel range of gas-powered and electric vehicles.

Findings

Table 1 summarizes the important results from all investigated half-stepped cylinders and their corresponding skin friction coefficients. The percent changes were calculated by comparing the results with the skin friction of the flat plate. For one-row cylinders, the lowest skin friction coefficients are when the diameter, spacing, and width are 0.0002 m, with over 7% reduction in the skin friction coefficient. With this width, having the cylinder diameter and spacing at 0.001 m and 0.003 m, respectively, increasing the number of rows to 20 results in a 10% decrease in the skin friction coefficient. For three-row cylinders, when the width and spacing of the cylinders are 0.001 m, the decrease in the skin friction coefficient is higher than 15%. Increasing the number of rows to 20 results in more than a 33% reduction in the skin friction coefficient. Considering the radius of the cylinder as the height of protrusions, in all these cases, the ratio of the cylinder's radius to the boundary layer thickness is less than 1%, and the spacing between the adjacent cylinders is more than 100 wall units. The cavity created by tandem cylinders has a width higher than the viscous sublayer, reducing the no-slip boundary conditions for multi-row cylinders. We hypothesize that with this spacing, the hairpin vortices responsible for instability and transition to a turbulent boundary layer are controlled, and the micro cavity reduces the no-slip boundary conditions for a significant reduction in the average skin friction coefficient.

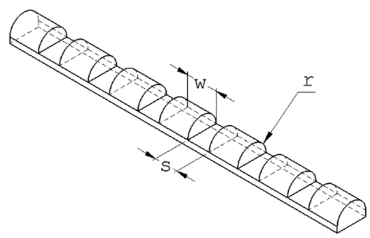
Policy/Practice Recommendations

California California has set goals to reduce greenhouse gas emissions 40% below 1990 levels by 2030 and significantly increase zero-emission vehicles by 2030. The executive orders N-19-19 and N-79-20 (1,2) require the Department of General Services to maximize the reduction of greenhouse gas emissions from the state fleet and promote zero-emission vehicle purchasing in state and local government fleets. Application of the present innovation reduces vehicle surface resistance, improves vehicle range, and reduces emissions. Travel range is increased in electric vehicles, which benefits both passenger and commercial vehicles. It is aligned with the goals of reducing greenhouse gas emissions from the transportation industry and improving air quality in California.

Table 1. The Change in the Average Skin Friction Coefficient of the Half-Stepped Cylinders

				Cf	0.002877				
Diameter	Spacing	Width (m)	N_rows	Upstream	Over	Between	After	Average	% Change
0.0002	0.0002	0.0002	1	0.0027	0.0027	0.0031	0.0023	0.0027	-7.56
0.0006	0.0002	0.0002	1	0.0025	0.0026	0.0041	0.0015	0.0027	-7.23
0.001	0.003	0.0002	20	0.0028	0.0026	0.0023	0.0027	0.0026	-10.0
0.001	0.0046	0.0006	20	0.0029	0.0026	0.0024	0.0027	0.0027	-7.4
0.0006	0.001	0.001	3	0.0027	0.0026	0.0024	0.0020	0.0024	-15.8
0.001	0.001	0.001	3	0.0026	0.0026	0.0024	0.0019	0.0024	-16.6
0.0014	0.001	0.001	3	0.0026	0.0027	0.0023	0.0021	0.0024	-16.2
0.001	0.0014	0.001	3	0.0026	0.0027	0.0027	0.0022	0.0025	-11.4
0.001	0.001	0.001	20	0.0024	0.0021	0.0012	0.0019	0.0019	-33.8

Figure 1. A Half-stepped Cylinder Row



About the Authors

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To Learn More

For more details about the study, download the full report at https://transweb.sjsu.edu/research/2525

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