ICCES, 2025, vol.33, no.2

Tech Science Press

DOI: 10.32604/icces.2025.011292

PROCEEDINGS

Research on Aerodynamic Drag Reduction of Urban Trains Based on Active Control of Wake Flows Using Air Blowing and Suction

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ABSTRACT

Energy efficiency and environmental sustainability in rail transit are key engineering goals. In urban trains, pressure drag plays a more significant role than in high-speed EMUs, primarily due to the blunt shape of the train’s head. The constraints imposed by underground construction and engineering protocols prevent the optimization strategies used in high-speed EMUs from being applied to urban trains. Therefore, aerodynamic drag reduction in blunt-tail urban trains, through active wake flow control, holds promise for improving train aerodynamics.

This study investigates drag reduction on the tail car of blunt urban trains using a hybrid numerical and experimental approach. The research focuses on the drag generation mechanisms, wake structure, and its evolution in the tail car. A blow/suction flow control method is proposed to manage wake vortices and reduce drag. The influence of control parameters on drag reduction is systematically analyzed.

First, the aerodynamic characteristics of blunt headed trains were analyzed using the k-ε method based on Delay Detached Eddy Simulation (DDES). The results show that the symmetric vortex pair formed at the tail leads to significant negative pressure and drag. A blow/suction method was introduced to control wake vortices. Centralized blowing was found to reduce pressure drag by 31.9%, leading to an overall drag reduction of 12.9%. Suction control reduced the total train drag by 10.3%, although it weakened the suction effect near the shoulder.

Additionally, the influence of blowing and suction parameters, such as speed and point of concentration, on drag was analyzed. Key findings include: (1) Increasing the suction range improves drag reduction, (2) The position of centralized blowing impacts vortex weakening, (3) Higher blowing and suction speeds lead to greater drag reduction, and (4) The position of the blowing point relative to the vehicle affects drag reduction performance.

Lastly, wind tunnel tests confirmed the numerical results, showing drag reductions of 14.57% and 11.53% for blowing and suction controls, respectively, validating the effectiveness of the proposed method.

KEYWORDS

Aerodynamic drag reduction; flow control; air blow/suction; numerical simulation

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.