Effects of Electric Forces due to Vehicle Electrification and Air Ions on the Surrounding Flow

Naohito Takasuka [1)] Kazuhiro Maeda [2)] Noboru Maeda [1)]

1) SOKEN Inc.
500-20 Minamiyama, Komenoki-cho, Nissin-city, Aichi, 470-0111, Japan (E-mail: naohito.takasuka.j2y@soken-labs.co.jp)
2) TOYOTA MOTOR CORPORATION
1 Toyota-cho, Toyota-city, Aichi, 471-8572, Japan

KEY WORDS: **Electrohydrodynamics (EHD), Charged air flow, Vortex shedding, Electrostatic field, CFD [D1]**

Electrostatic charging of vehicles during driving has been suggested to influence the surrounding airflow, potentially affecting vehicle stability, handling performance, and aerodynamic noise. However, the physical mechanism by which electric forces arising from vehicle electrification and naturally existing air ions interact with the flow field has not been fully clarified. In this study, the effects of electric forces generated by vehicle charging and air ions on flow behavior and surface pressure fluctuations were investigated through numerical simulations and wind tunnel experiments.

A simplified two-dimensional step geometry, representing a generalized vehicle surface feature and modeled as an electrical insulator, was employed. Unsteady numerical simulations were conducted using COMSOL Multiphysics, in which the fluid flow field, electrostatic field, and charge transport field were strongly coupled (Fig. 1). The step surface was subjected to applied electric potentials of 0 V, −0.1 kV, −1 kV, and −2 kV, while naturally occurring small air ions were introduced into the flow. In parallel, wind tunnel experiments were performed using an identical step model, where surface pressure fluctuations were measured under uniform flow conditions with and without ion injection (Fig. 2).

The numerical results showed that flow separation occurred at the step edge, followed by vortex shedding and downstream reattachment. The vortex shedding behavior was strongly influenced by the applied electric potential. In particular, under the −1 kV condition, the vortex shedding became most stable and periodic, leading to stabilized surface pressure fluctuations and a reduction in low-frequency pressure components. At higher applied voltage (−2 kV), the vortex formation and shedding location gradually shifted downstream, indicating a change in the flow structure. The experimental results also demonstrated a reduction in low-frequency pressure fluctuations when an electric potential was applied, and this tendency qualitatively agreed with the simulation results, although differences in peak frequency and amplitude were observed due to three-dimensional effects and inflow disturbances in the experiments (Fig. 3, Fig. 4).

Further analysis based on the Navier–Stokes equations revealed that the electric force acted locally within the separated flow region downstream of the step edge, particularly near the surface where the flow velocity was low. In this region, the relative contribution of the electric force became significant compared with pressure gradient and viscous forces. As a result, vortex growth and merging were suppressed, promoting smaller and more periodic vortical structures and reducing low-frequency unsteady pressure fluctuations.

These findings demonstrate that electric forces induced by vehicle electrification and air ions can locally modify separated flow structures and pressure fluctuation characteristics. The present study provides a physical explanation of how relatively small electric forces can influence vehicle-scale flow phenomena and suggests the potential for flow stabilization through controlled electrostatic effects.

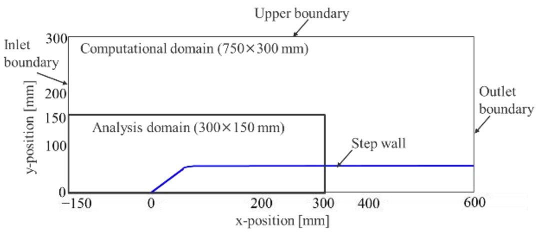

Fig. 1 Simulation Model

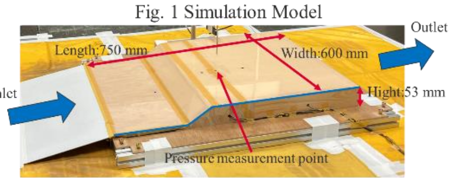

Fig. 2 Experimental model

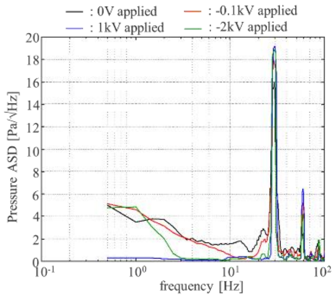

Fig. 3 Simulated pressure ASD at x = 220mm

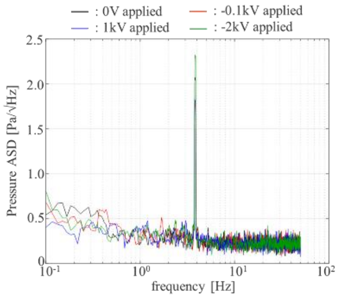

Fig. 4 Experimental pressure ASD at x = 220mm