

Analysis Method for Airflow around a Vehicle Considering Electrostatic Charging, Surface Ion Neutralization, and Electrostatic Force Fluctuation by Vehicle Motion

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.j2v@soken-labs.co.jp)

²⁾ TOYOTA MOTOR CORPORATION

1 Toyota-cho, Toyota-city, Aichi, 471-8572, Japan

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Driving-induced electrostatic charging on vehicle has been reported to influence surrounding airflow through electrostatic interactions with naturally occurring air ions. Previous studies have shown that steady electric forces generated around a charged vehicle can modify vortex-shedding behavior and affect surface pressure fluctuations. However, actual electrostatic charging on vehicle is inherently unsteady because both the vehicle surface potential and charge neutralization continuously vary during driving. As a result, the electric force acting on the surrounding airflow is also expected to fluctuate with time, although its influence on aerodynamic behavior has not yet been fully understood.

In this study, a time-dependent multiphysics simulation was performed using COMSOL Multiphysics by strongly coupling fluid flow, electrostatics, and charge transport. A simplified two-dimensional step model representing a vehicle surface discontinuity was analyzed under a freestream velocity of 10 m/s while considering naturally occurring air ions. Periodic surface-potential fluctuations of 0.5, 1, 2, and 4 Hz were imposed around a mean potential of -1 kV with an amplitude of ± 1 kV. In addition, the influence of charge neutralization was investigated by varying the charge-removal rate on the charged surface. The aerodynamic response was evaluated using the pressure amplitude spectral density (ASD) obtained from the unsteady pressure signal (Fig. 1).

The simulation results showed that surface-potential fluctuations at 1–4 Hz increased low-frequency pressure fluctuations compared with the DC and 0.5 Hz conditions. Spectral analysis of the electric force revealed that the distinct peak associated with the natural vortex-shedding frequency of approximately 30 Hz disappeared when the surface potential fluctuated. This indicates that temporal variations in electric force modified the vortex-shedding process, resulting in enhanced low-frequency pressure fluctuations around the charged surface (Fig. 2).

The effect of charge neutralization was also significant. Increasing the neutralization level increased low-frequency pressure fluctuations. Electric-force analysis showed that stronger neutralization reduced the amount of charge accumulated near the surface, thereby weakening the electric force that attracted airflow toward the charged wall. Consequently, the stabilizing effect of the electric force on the separated flow decreased, leading to an increase in pressure fluctuations (Fig. 3).

These results demonstrate that temporal variations in electric force caused by surface-potential fluctuations and charge neutralization can significantly influence vortex-shedding behavior and low-frequency aerodynamic fluctuations around an electrified vehicle body. The proposed multiphysics simulation framework provides an effective method for evaluating aerodynamic phenomena associated with driving-induced electrostatic charging on vehicle and contributes to a better understanding of electrohydrodynamic effects in automotive applications.

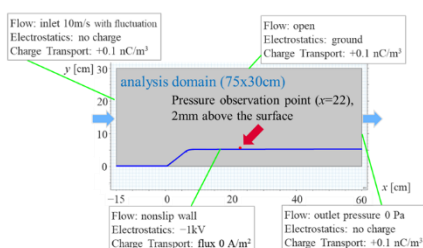


Fig.1 Simulation Model

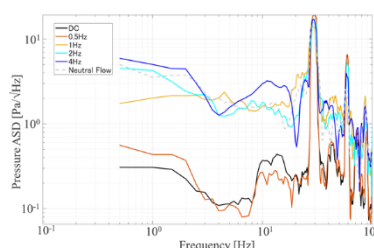


Fig.2 Pressure Amplitude Spectral Density during Potential Fluctuations

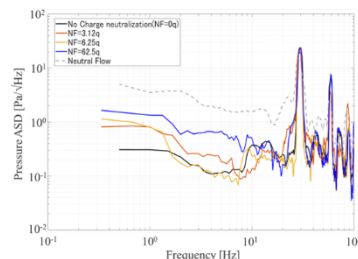


Fig.3 Pressure Amplitude Spectral Density during Charge Neutralization Fluctuations