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A Study on Quantitative Evaluation Methods for Assessing the Impact of Individual Vortical Flows around a Vehicle on Aerodynamic Drag

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Reducing aerodynamic drag is a critical issue for improving vehicle fuel efficiency. Although vortices generated around a vehicle body are a major factor contributing to drag increase, suppressing all such vortices is impractical because vehicle shape design must satisfy constraints related to styling, cabin space, and drivability. The objective of this study is to establish a method for quantitatively evaluating the contribution of individual vortices around a vehicle to drag, and to identify effective areas for design improvements aimed at reducing aerodynamic drag. To achieve this objective, a vortex-induced drag evaluation method was combined with a vortex identification method. Based on this combination, a method for quantitatively visualizing the drag generated by individual vortices was developed. The proposed method was validated using the flow fields around a simplified vehicle model (Ahmed model). In the proposed method, aerodynamic drag was evaluated using the wake integration method based on the momentum conservation law. By rearranging the equation, the drag component attributable to vortical structures was extracted. The extracted vortex-induced drag component is expressed as:

$$D_v = \frac{1}{2}\rho \int_S \psi\omega_x dS\,. \tag{1}$$

Moreover, in the proposed method, the sectional-pressure-minimum-and-swirl method was employed to identify the positions of individual vortices generated around a vehicle. In this method, points where the pressure is locally minimized and the surrounding fluid simultaneously satisfies the vorticity condition are detected as vortex centers, as shown in Fig.1. Because both pressure and rotational motion are taken into account, this method enables the extraction of regions where vortex flow occurs. A vortex center line is constructed by connecting the vortex center points. The vortex center lines coincide with the maximum value of $\psi\omega_x$ as shown in Fig.2. Finally, by integrating $\psi\omega_x$ around a vortex line, the drag coefficient of each vortex was quantitatively evaluated, as shown in Fig.3.

Furthermore, the proposed method was also applied to the flow field around an SUV model to demonstrate its capability in a more realistic flow field. The results of assigning drag coefficients to the centerlines of each vortex around the SUV model are shown in Fig. 4.

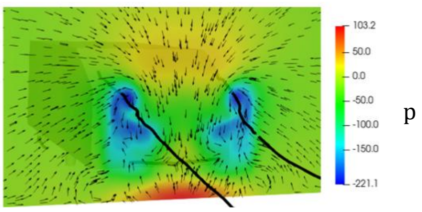

Fig.1 Vortex centerlines and cross-sectional flow fields behind the simplified vehicle model.

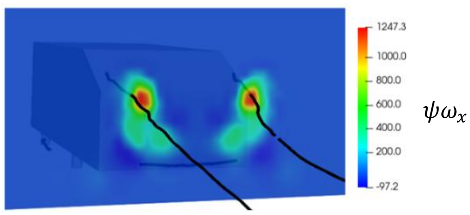

Fig.2 Vortex centerlines and cross-sectional distribution of $\boldsymbol{\psi\omega_x}$ behind the simplified vehicle model.

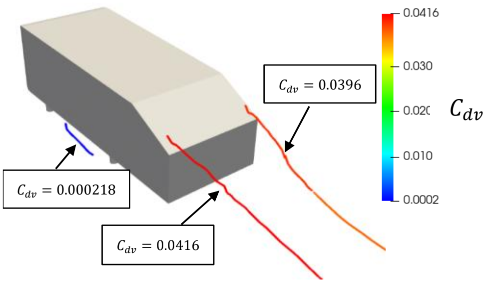

Fig.3 Vortex centerlines around the simplified vehicle model, colored by assigned resistance contributions.

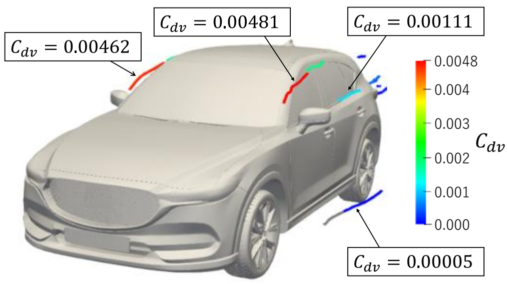

Fig. 4 Vortex centerlines around the SUV model, colored by assigned resistance contributions.