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Investigation of Airflow Characteristics in Simplified Vehicle Cabin During Fresh Air Rate Contorol Using Stereo PIV Visualization

Kosuke Onishi [1)]　Takuji Nakashima [1)]　Kazuki Ito [1)]　Hidemi Mutsuda [1)]

1) Hiroshima University, Graduate School of Advanced Science and Engineering
1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527, Japan

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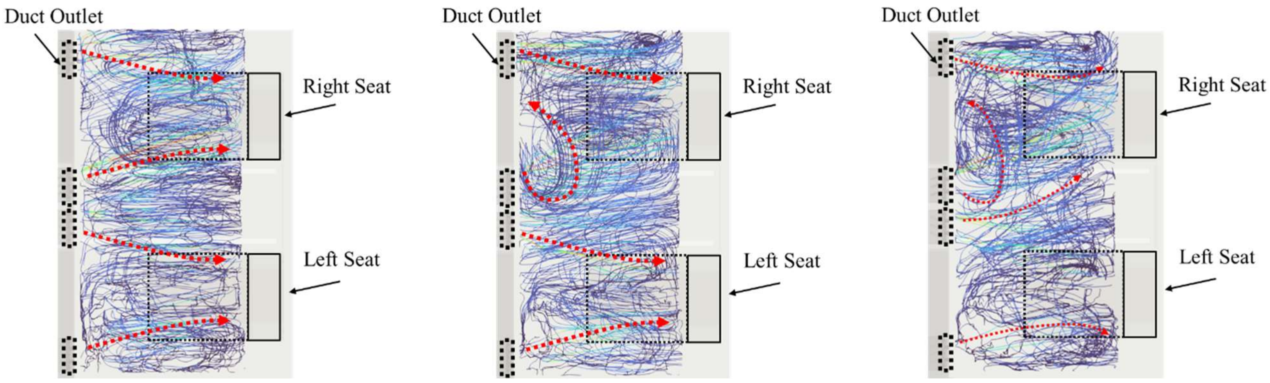
To achieve carbon neutrality by 2050, improving the energy efficiency of automotive air conditioning systems has become increasingly important. In particular, in electric vehicles (EVs), the use of air conditioning significantly reduces energy efficiency, potentially decreasing the driving range by up to approximately 25%. Moreover, HVAC energy consumption is estimated to account for around 15% of the total vehicle energy usage.Within the vehicle cabin, airflow discharged from the air vents interacts with interior components, forming complex three-dimensional flow structures. Therefore, a detailed understanding of these flow fields is essential for enhancing both thermal comfort and energy efficiency. However, previous studies have predominantly relied on two-dimensional measurements, limiting comprehensive analysis.

In the present study, exhaust conditions corresponding to the fresh air rate were defined by three exhaust flow ratios (0%, 50%, and 100%) at both the rear of the cabin and the front footwell. Assuming the maximum airflow rate of an actual vehicle, airflow velocity discharged from the air vents was determined by matching the Reynolds number at the air vent outlet.

The measurement domain was defined as the region above the front seats, where velocity measurements were conducted at 10 mm intervals within a height range of 160 to 550 mm from the floor, resulting in a total of 40 cross-sectional planes. At each cross-section, 600 image pairs were acquired and processed using stereo PIV. The three-dimensional velocity field was then reconstructed by time-averaging the instantaneous velocity data and spatially stacking the velocity distributions on the cross sections.



(a)　0%　　　(b)　50%　　　(c)　100%

Fig.1　Comparison of streamlines at fresh air rates of 0%, 50%, and 100%.

The flow field throughout the cabin shown in Fig.1(a) exhibits symmetry about the vehicle centerline. This symmetry is attributed to the outlet configuration in the outside air intake mode, where outlets located at the rear of the cabin are arranged symmetrically on both sides. As a result, airflow is discharged evenly, leading to the formation of a symmetric flow field within the cabin. From the flow field throughout the cabin shown in Fig.1(b), it is evident that a vortex structure develops near the front-center region, inducing a lateral airflow from the left side toward the right. This behavior can be attributed to the influence of the outlet located in the front passenger footwell on the right side, operating under recirculation mode. As shown by the streamlines in Fig.1(c), the circulation flow observed at the fresh air rate of 50% has become more pronounced.

It was confirmed that, as the outside air intake rate decreases, a transverse flow is induced across the cabin, directed from the passenger side toward the driver’s side. This flow is presumed to include an upward vertical component near the center of the cabin and a downward flow along the driver’s side. Furthermore, this lateral circulation within the cabin is considered to deflect the airflow from the driver-side outlet downward, while the airflow from the two central outlets is deflected upward.