Investigation of Vehicle Cabin Airflow Characteristics for Pre-Conditioning Efficiency Enhancement Using CFD and Proper Orthogonal Decomposition

Kazuki Ito [1)] Hikaru Nishikokura [2)] Takuji Nakashima [1)] Kosuke Onishi [1)] Hidemi Mutsuda [1)]

1) Hiroshima University, Graduate School of Advanced Science and Engineering
1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527, Japan
2) Hiroshima University, Graduate School of Advanced Science and Engineering (at the time of the study)

KEY WORDS: **Heat･fluid, Air conditioner, Interior environment,** Computational fluid dynamics, POD, Pre-conditioning [D1]

Improving passenger comfort within the vehicle cabin while ensuring an adequate driving range through enhanced air-conditioning efficiency remains a critical challenge. In recent years, certain vehicles have been equipped with pre-conditioning systems that cool or heat the cabin prior to passenger entry, as well as defogging functions for windshield. Particularly under summer conditions, the early removal of hot air from the cabin is effective in reducing the load on the air-conditioning system.

A total of 170 conditions were analyzed using computational fluid dynamics (CFD) by varying the ventilation modes and airflow directions of the HVAC system. The computational model employed a simplified half-scale cabin geometry. Regarding air-conditioning conditions, the fins of the ventilation duct louvers were adjusted in both vertical and horizontal directions to control the airflow orientation. Air was discharged from outlets located at the front footwell and the rear of the cabin, and the distribution ratio of airflow between these outlets was varied from 0% to 100%. The CFD results were further analyzed using data-driven techniques based on Proper Orthogonal Decomposition (POD) to evaluate their influence on ventilation performance. Fig.1 presents the spatial characteristics of Mode 2, in which the airflow from the outlet is deflected laterally. A positive mode coefficient corresponds to airflow directed toward the driver side, whereas a negative coefficient indicates airflow toward the passenger side.

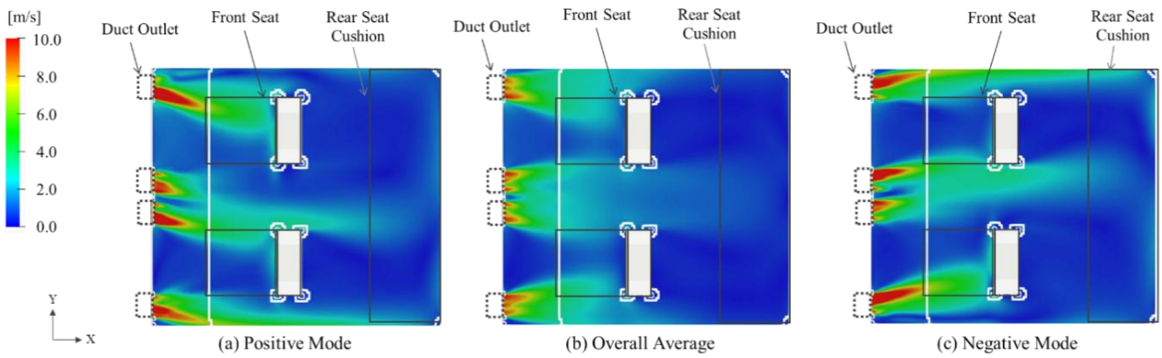

Fig.1 Flow Field the Vehicle Cabin in Mode 2 Obtained by POD

Based on the POD results, a neural network was trained to model the relationship between control parameters and the resulting mode coefficients, as well as the air residence time in each zone, which were defined as objective functions. Fig.2 shows the time required for the residual air fraction within the cabin to decrease to 10% or less. Fig.3 shows the the distribution of the retention rate of the initial air inside the cabin. The results demonstrate that high-accuracy surrogate models based on POD and neural networks can be effectively utilized for investigating improvements in cabin ventilation performance.

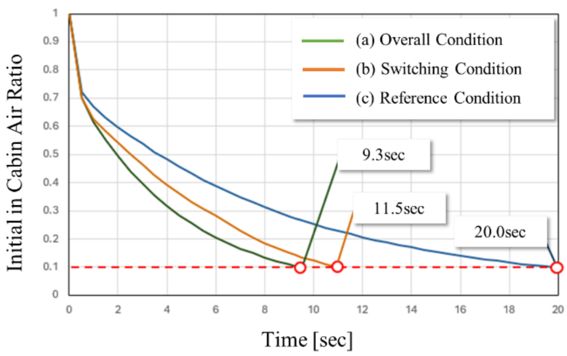

Fig.2 Time to Remove Residual Air from the Cabin

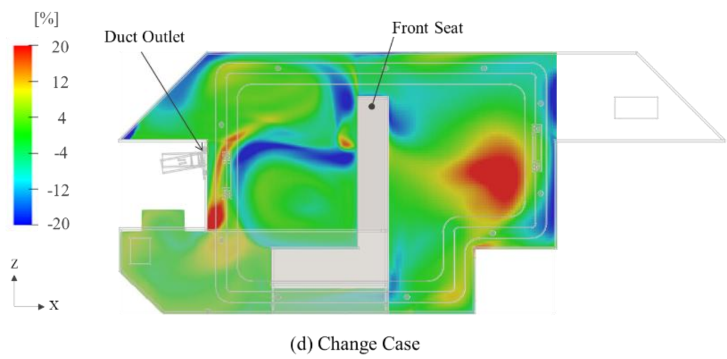

Fig.3 Initial Air Retention Rate Distributution Inside the Cabin