Numerical Study of Cooling Air Flow Distribution in Car Cabin

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Abstract

This numerical study aims to investigate the performance of car air-conditioning (AC) cooling of cabin car. The research was done in the two-step. The first step is to collect data by experiment study. Numerical study of performance car air-conditioning is the second step. Detached Eddy Simulation k-epsilon (DES k-ε) turbulence model was utilized in the study. A cabin car design was used as a specimen study. Two key parameters, i.e. temperature distribution, and air cooling speed, were used to assess the AC cooling performance compared with experimental data. Two types of mesh (mesh A and B) with different smooth was utilized. The results showed that mesh B gave good agreement with experimental data with a discrepancy of 0.14%, and 0.27% with mesh A. Air cooling distribution at three measured positions are 0.47; 0.08; and 0.04 m/s, respectively.

Keywords: AC, DES, mesh, temperature

Abstrak

*Studi numerik ini bertujuan untuk mengetahui kerja dari pendingin udara (*AC*) pada mobil. Riset ini diselesaikan dalam dua langkah. Langkah pertama berupa pengumpulan data dengan studi eksperimen. Studi numerik terkait kerja pendingin udara (*AC*) sebagai langkah kedua. Pemodelan turbulent* Detached Eddy Simulation k-epsilon *(*DES k-ε*) digunakan pada studi ini. Dua parameter yang digunakan untuk mengetahui kerja pendingin udara (*AC*) yaitu distribusi suhu dan kecepatan pendinginan udara akan dibandingkan dengan data eksperimen. Dua macam mesh (mesh A dan mesh B) dengan kehalusan yang berbeda telah digunakan. Hasilnya menunjukan bahwa mesh B memberikan hasil yang lebih baik jika dibandingkan dengan data eksperimen dengan perbedaan sebesar 0,14% dan 0,27% dengan mesh A. Distribus pendingin udara yang diukur pada tiga posisi berbeda adalah 0,47 m/s; 0,08 m/s dan 0,04 m/s bertuturt-turut.*

Kata kunci: AC, DES, *mesh, suhu*

1. Introduction

The level of vehicle comfort, especially a car, is a necessary attention aspect for automotive manufacturers. Some of its such as interior design, ergonomics, suspension, and air conditioning in the cabin. Air Conditioning (AC) is a technology that is applied to create comfort in the car. The working principle of its is using a steam compression process. In this system, there are four main components, i.e evaporator, compressor, condenser, and refrigerant flow control device. Each component has different characteristics and functions, but is integrated and operated together will create a condition of thermal comfort in the car. The impact of using a refrigeration system on an object is that if some of the energy contained therein is taken, the object's temperature will decrease. Conversely, because the absorbed thermal energy is transferred to the environment, it can become warmer. To create comfortable conditions and good air distribution, the distribution of airflow and thermal load is a necessary factor [1]. The cooling load of a car air conditioner issues from several sources, such as the period of solar radiation, the load from the type of material in the car cabin, and the number of passengers in it. Alahmer et al [2], use an evaporative system design to investigate the effects of relative humidity (RH) and temperature control on thermal comfort in the vehicle cabin. The results showed that the change of relative humidity in the vehicle cabin could increase air conditioning efficiency by reducing heat transfer, thereby increasing user comfort. The speed and temperature of the air from the evaporator affect the comfort level in the cabin [3] [4] [5]. Zhang et al [6] conducted research on the effect of differences in air supply velocity on the decrease in temperature in the room, with the results, obtained that the highest level of comfort occurs when the air supply velocity is between 1.75-2 m / s. The study done by Khayyam et al. [7] focused on reducing energy consumption and increasing the efficiency of AC in cars using a system called "an intelligent adaptive air conditioning control system". This system is used to control the operation of the air conditioner, blower and circulation of air in the cabin so that a comfortable condition, as well as clean air circulation, is achieved in the cabin. Jasni and Nasir [8] conducted an experimental study related to the reduction of car cabin temperature using three methods, i.e by using sunshades, ventilators and window tints. The results showed that used window tints provided the most optimal temperature reduction in the cabin compared to sunshades and ventilators. Research on air conditioning has been carried out, both experimentally or simulations. The simulation approach provides convenience in the research process, needed is shorter time and easy to repairs if something goes wrong it is. Li and Sun [9] perform simulations related to the level of comfort in the vehicle cabin. Some of the variables used as analysis and simulation data include environmental conditions, conditions in the cabin, car speed, clean air volume, solar time, and passengers in it. Simulation research has also been conducted by Kumar et al. [10] which focused on the shape and position of the coolant duct. The results showed that the position of the coolant channel has more effect on the comfort inside the vehicle cabin than the shape of the coolant channel. Based on several literature studies that have been described above in this numerical study focused on cooling performance in the cabin. The main parameters, i.e the distribution of temperature and air velocity in the cabin. Furthermore, the simulation results are compared with experimental data.

2. Methods

The research begins with experimental data collection, such as the temperature distribution in the car cabin. The car used is a minibus type with single blower air conditioning with the speed of airflow is 2 m / s. The temperature measurement position is located at three points, that is the front cabin (position 1, coordinate x;y = -850; 0), the middle cabin (position 2, coordinate x;y = 0; 0) and the rear cabin (position 3, coordinate x;y = 0; 850). The measurement result data is shown in Table 1.

Table 1. Measurement data

Measurement Position	Temperature (ºC)
Initial temperature in the cabin	34
Front cabin	33.1
Middle cabin	33.4
Rear cabin	33.6

The next step is to conduct simulation research on AC performance. Before doing the simulation, a 3-D car cabin design is needed. The car cabin geometry is made identical to the actual conditions. Some of the characteristics of the boundary conditions used in the simulation process are shown in Table 2. The 3-D design of the car cabin is shown in Figure 1.

Table 2. Boundary conditions

Position	Boundary condition
Cabin wall	Wall (no slip)
Front seat	Wall (no slip)
Middle seat	Wall (no slip)
Rear seat	Wall (no slip)

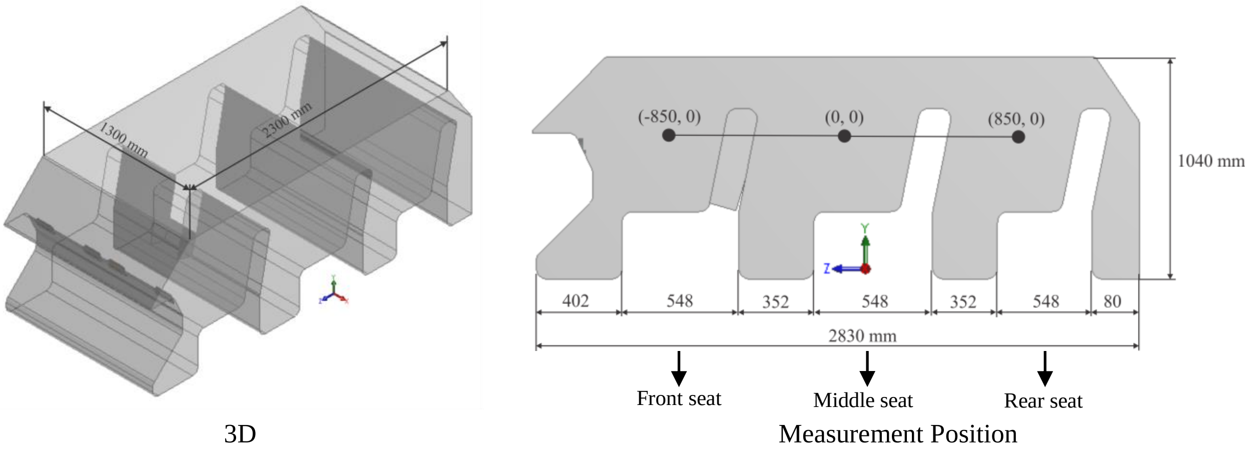
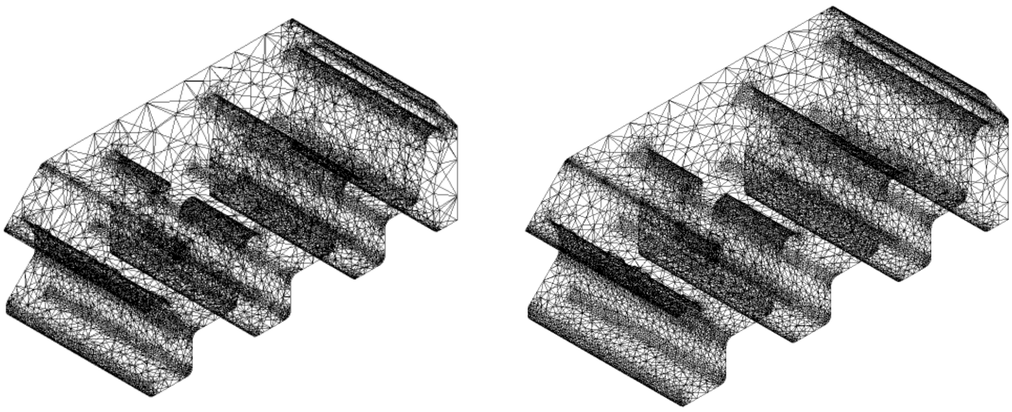


Figure 1. Cabin Design

In this study, two different mesh levels were used, for the number of nodes and elements in each mesh can be seen in Table 3. This difference of mesh aims to evaluate the type of mesh that produces good agreement with experimental data. Figure 2 shows the mesh of the test specimens used in this study.

Table 3. Characteristic mesh

Mesh type	Number of nodes	Number of elements
A	32088	140758
B	44249	202251



Mesh A   *Mesh* B

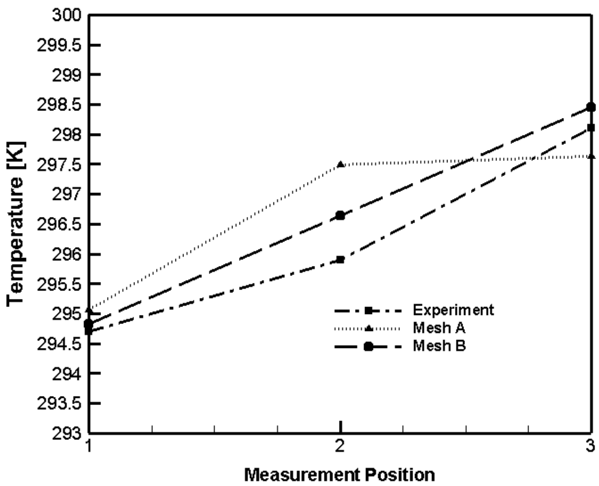
Figure 2. Meshing

3. Results and Discussion

The validation step aims to evaluate the mesh that provides good agreement simulation results by the experimental data used as a reference. The parameter used as a measure of cooling performance is the temperature distribution in the cabin. The results of the research can be described as follows.

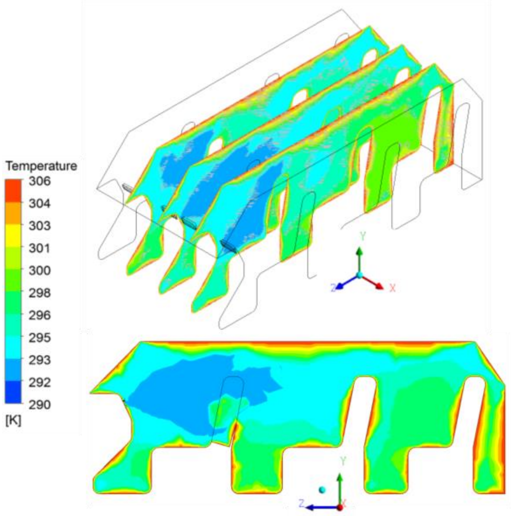
3.1 Mesh Validation

Figure 3 shows the results of the mesh validation. The parameter used as a measure of cooling performance is the temperature distribution that occurs at three measurement points, specifically the front (position 1), middle (position 2) and rear (position 3) cabin. The speed of the airflow from the evaporator is 2 m / s. The results showed that the difference in the mesh level has an effect on the temperature distribution in the cabin. The simulation results using mesh A occur "over-prediction" at measurement positions 1 and 2, then "under-prediction" occurs at measurement position 3. The discrepancy between the results of the study and the experimental data was 0.27%. The results of mesh B have the same trend and are close to the experimental data. The discrepancy with experimental data is 0.14%. Based on the outcome that has been obtained, so mesh B provides better results than mesh A, so that mesh B can be used to analyze the cooling performance of the air conditioner in the cabin.



Gambar 3. Mesh validation

Figure 4 shows the contours of the temperature distribution inside the cabin. The average temperature at the front, middle and rear cabin is 21.8^{0}C, 23.6^{0}C, and 25.4^{0}C, respectively. The highest cooling effect occurs in the front cabin because of a single blower air conditioner positioned on the front dashboard. It makes the distribution of airflow that circulates a lot in the front cabin.



Gambar 4. Contour temperature distribution inside the cabin

3.2 Airflow Distribution in the Cabin

The distribution of airflow in the cabin can be seen in Figure 5. The direction and velocity of airflow are visualized in vector form. The air flowing out through the four evaporator channels has different characteristics. The coolant airflow from channels 1 and 4 hits the front seats, causing a deflection of the flow towards the roof of the cabin. It causes the temperature in the front cabin to be lower than the middle and rear cabins. Airflow from channels 2 and 3 can flow to the central and rear cabin through the gaps between the left and right seats in the front cabin then there is recirculation of flow towards the front dashboard. The airflow velocity in the front, middle and rear cabins is 0.47, 0.08, and 0.04 m / s, respectively.

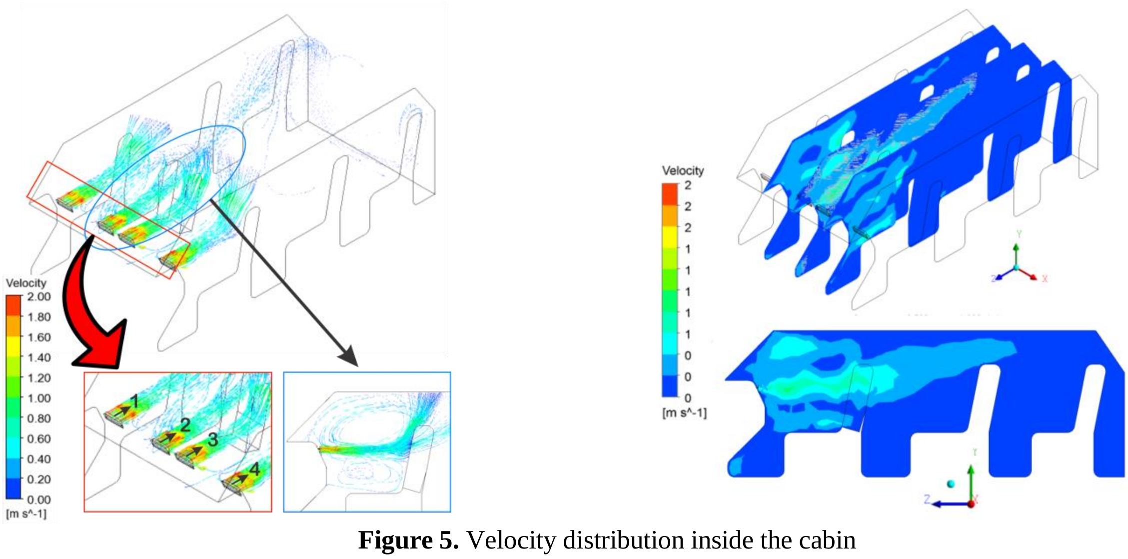


Figure 5. Velocity distribution inside the cabin

4. Conclusions

A numerical study with applied the DES k-ε turbulence model has been identified two necessary parameters for testing the cooling performance of air conditioners in-car cabin. Validation shows that mesh B provided simulation results that match the experimental data. The cooling effect is evenly distributed from the front to the rear cabin. The cooling effect is highest on the front cabin. It is due to a single blower air conditioner which causes the cooling air circulation to be more concentrated in the front cabin. The cooling effect is also influenced by the magnitude of the cooling airflow velocity in the cabin. The cooling effect increases with increasing airflow.

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