

Numerical Simulation Research on Pressure during Door Closure of Commercial Vehicle

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ABSTRACT

The magnitude of door closing force is important in vehicle NVH characters, and in most case, it is not fully studied by computer aided engineering (CAE) in an early developing stage. The research took a heavy-duty truck as the study object and used Computational Fluid Dynamic (CFD) method with dynamic mesh to analyze the flow field of the cabin during door closing process. The change trend of pressure with time was obtained, and the influence of different factors was studied. The experiments were conducted to verify the results. Results show that the velocity of closing door and the size of relief holes have a significant influence on cabin interior pressure, and greater velocity leads to larger the pressure in cabin. The initial angle of the door affects interior pressure less comparing with the velocity of closing door. The interior pressure could be reduced effectively with the method of decreasing the velocity of closing door and increasing the size of relief holes.

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INTRODUCTION

The role of commercial vehicles in logistics transportation is more and more important in the modern economy. The comfort requirement of commercial vehicles is raised gradually, as the living standards improve. The magnitude of the door closing force is an important factor affecting the whole vehicle riding comfort. The door should be sealed and reliable when it is closing. However, the air tightness contradicts the magnitude of door closing force [1]. The magnitude of door closing force is affected by a variety of factors including air resistance effect, sealing strips, door locks, door limiting stopper, gravity of the door and so on [2, 3, 4, 5, 6]. Reference [3] showed that the contribution of air resistance effect on the magnitude of door closing force reaches 30% to 50% among these factors. Part of the air is pushed into the cabin in the door closing process and the interior pressure rises instantly because the interior air is compressed from door contracting the sealing strips to closing completely, which is called air resistance effect. Thus, a pressure relief valve is used generally to reduce the effect of door closing on pressure increasing in the cabin which can be achieved by opening the pressure relief valve and excluding the excess air when the pressure reaches the set pressure value. Though the set pressure value of the pressure relief valve has a great effect on pressure change during door closing

process, the method of determining the size of the set pressure value has been seldom studied in China. Theoretical calculation and experimental methods are always adopted to assess the door closing characteristics in the early period of the vehicle development in China. Experimental method is high cost and lacks real-time monitoring capability. Gao et al. [2] programed and computed the pressure change in a passenger car on the basis of theoretical analysis method, and determined the energy consumed by air resistance effect. Yin et al. [5] calculated the influence of air resistance effect on door closing force according to the compression equation of gas. Zhang [12] adopted CFD simulation to investigate the variation of pressure inside the passenger compartment of a passenger car through door closing process.

Theoretical and experimental methods are mostly employed to study the aerodynamic drag in the door closing process of passenger cars in present and little attention has been focused on this phenomenon in commercial vehicle [6, 7, 8, 9, 10, 11, 12]. In this article, CFD software Fluent and dynamic mesh technique were used to perform the transient simulation analysis on the interior field of a heavy-duty truck cabin, which revealed the unsteady movement of flow in the door closing process and captured the max value of aerodynamic

drag. The variation of pressure on the inside surfaces of driver's door and cabin were investigated and the relation between variation of pressure on the inside surface of driver's door and factors such as area of relief holes of the cabin, angular velocity and initial angle of the door was analyzed, which provides a reference for the design of the pressure relief valve of the cabin.

MODEL

A heavy-duty truck cabin model was selected as the research object. According to the actual dimension of the truck, the length L of the cabin model was 1750 mm, the width was 2050 mm and the height was 1815 mm, shown in Figure 1. As close to the actual, seats and sleeping berth with actual size were placed inside the cabin. The initial angle of the door was 77.55° .

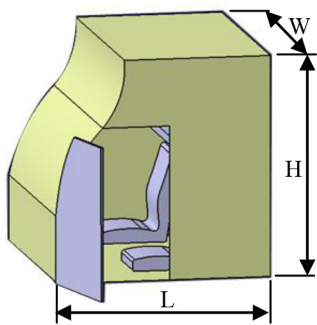


Figure 1. 3D model of the cabin.

NUMERICAL SIMULATION

Dimension of Computational Domain

It was assumed that the cabin was located on the open road. Considering the balance of computing precision and computing time, a cube with 20000 mm side length was used as computational domain to prevent the exterior air flow from disturbing the flow field around the cabin. The dynamic mesh technique provided by Fluent was used to update computational mesh dynamically during rotating motion of the door. Because the deformation of cells near the rotary shaft of the door was large, mesh refinement was conducted on the door and inside the cabin in order to prevent large distortion and negative volume during the motion. When the door closes completely, the interval between the door and cabin should be zero, which means the edges of them would overlap. Because of the functional limitation of Fluent, however, the boundary condition can't be changed during the calculation, which indicates that zero interval can't be achieved. Hence, an interval of 3 mm was left between the door and the cabin under complete close to guarantee the calculation could be carried out smoothly [13].

Pre-processing software Gambit was used to mesh and tetrahedral unstructured mesh was chosen for discrete of the computational domain. Tetrahedral unstructured mesh is convenient in adaptability and mesh generation and is suitable for dynamic mesh technique [14]. The cells inside and around the cabin were refined so as to capture the flow near the door and 3.7 million cells were generated totally, shown in Figure 2.

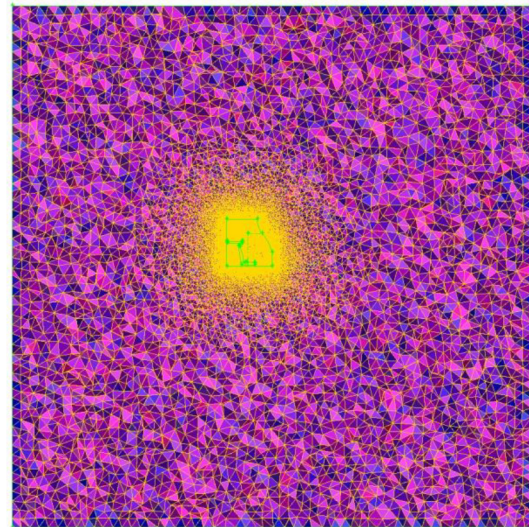


Figure 2. Mesh distribution in the domain.

Turbulence Model

SST $k-\omega$ turbulence model was selected to capture the flow field structure. SST $k-\omega$ model, the combination of $k-\epsilon$ and $k-\omega$ models, adopts $k-\omega$ model in the near wall and $k-\epsilon$ model in the far field. A blending function, considering wall distance and parameters of turbulence, is used to realize the transition from near wall $k-\omega$ model to far field $k-\epsilon$ model for SST $k-\omega$ model [15]. In the door rotating process, there is severe flow separation in the boundary layer of it and SST $k-\omega$ model was also chosen for the high efficiency on capturing the flow separation.

When the door is closing, part of the exterior air is pushed into the cabin and the interior air is compressed in a very short time. In this process, it is reasonable to be seen air as ideal gas [12] [16]. 3D double precision transient solver was chosen and fluid material was defined as ideal gas. Spring smoothing and local cell remeshing were used in the dynamic mesh. The outlet of the computational domain was set to pressure outlet with 0 Pa gauge pressure and the door was assumed as rigid body, whose movement was control by a profile document. Pressure and transient formulation were second order.

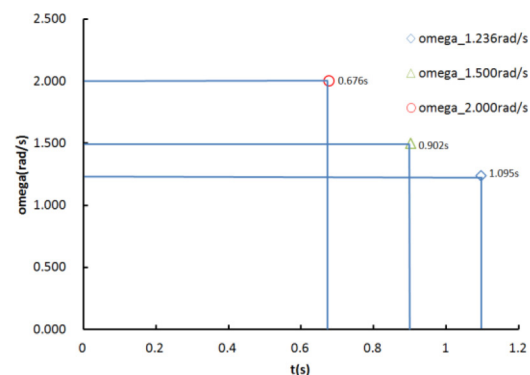


Figure 3. The door closing time under different angular velocities.

The experimental results showed the velocity of closing door for a commercial vehicle ranged from 0.8 to 1.5 m/s. Therefore, the angular velocities of the door (ω) were set as 1.236 rad/s, 1.500

rad/s and 2.000 rad/s. According to the initial angle, the door closing time under different closing velocities could be calculated, shown in Figure 3.

In order to obtain the exact pressure distribution in the moment the door closed, the following equation was adopted to calculate the time step Δt needed in the simulation.

$$\Delta t = \frac{L}{v} C \quad (1)$$

Where L is the minimum size of cells; v is the velocity of air; and C is courant number.

In this research, the minimum size of cells was 30 mm, the velocity of air was below 10 m/s and courant number was 1. As a result, a time step of 0.003 s or shorter could meet the need in this situation. Thus, the time step was set as 0.001 s for capturing the separated flow structure and there was 20 iterations in each time step.

RESULT ANALYSIS

Effect of the Velocity of Closing Door

The average value of pressure on the inside surface of the door was taken as the evaluation objective to analyze the effect of the velocity of closing door on pressure distribution in the cabin. Figure 4 shows the variation of pressure in the cabin with time for different angular velocities. In Figure 4, pressure is steady and remained in a low value before the door closed. Later, pressure rises suddenly in the moment that the door is fast closing and reaches the maximum value at the time point that the door closed. Then pressure drops to the atmospheric pressure rapidly and comes to stabilization soon. The maximum interior pressure in the cabin varies as the velocity of closing door changes and the faster the door closes, the higher the maximum interior pressure reaches.

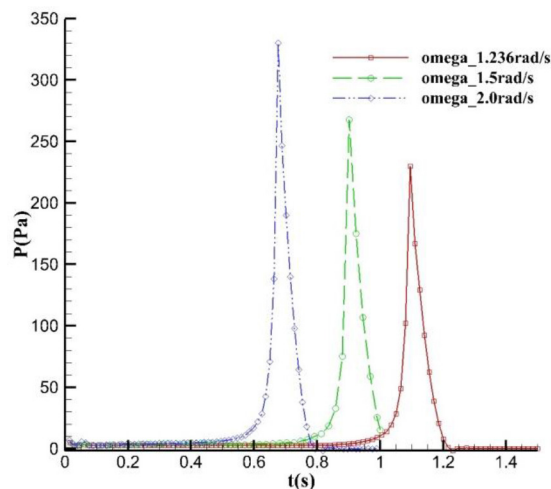


Figure 4. Variation of pressure in the cabin with time for different angular velocities.

A research on pressure variation of a passenger car in door closing process was carried out by Lee and Hwang [16] and got results from numerical simulation, shown in Figure 5, which are similar to this study.

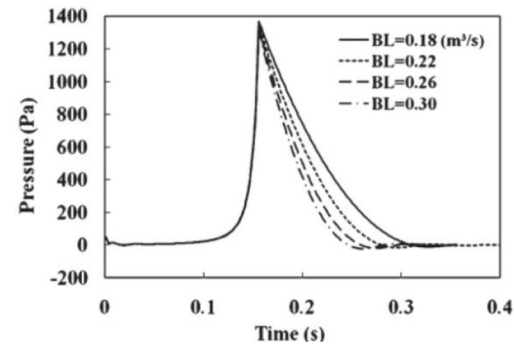


Figure 5. Results of simulation by Lee and Hwang.

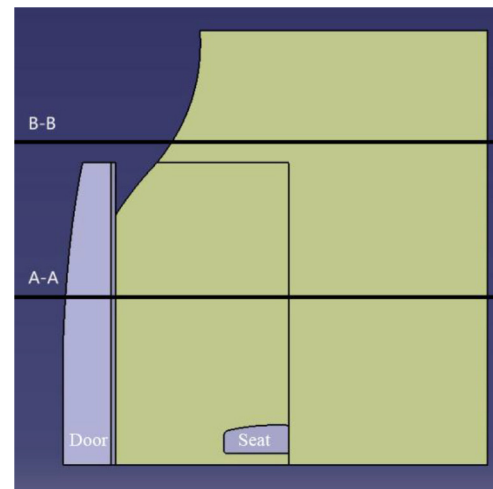


Figure 6. Locations of section planes.

Section planes of $z = 0.7$ m (A-A) and $z = 1.35$ mm (B-B) were taken for analysis, shown in Figure 6. Static pressure contours of different moments in section plane A-A under 1.236 rad/s angular velocity is displayed in Figure 7. At the beginning of door closing, pressure in the cabin rises and becomes nonuniform because the air near the door is disturbed. Pressure stabilizes around atmospheric pressure as the closing motion is going on. When it is fast closing, pressure increases sharply and then reduces quickly to about atmospheric pressure after the door closed.

Table 1 shows the aerodynamic drags in the door closing moment under different closing angular velocities. It is found from Tab. 1 that the aerodynamic drag of the door increases rapidly as the velocity of closing door increases. Accelerating the velocity of closing door will shorten the time air overflows from the cabin and reserves more air inside the cabin, which indicates the air inside the cabin suffers a stronger compression and produces a larger reaction force on the door.