On pressure drop and airflow directivity ability of air vents on automobile cabinets

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Abstract: *In this study, airflow directivity ability and pressure drop values of air vents where placed on the front console of automobile cabinet were investigated with computational fluid dynamics analysis. One of the aims of these studies is the airflow performance impact of design changes on air vents. Therefore, parametric studies were conducted with diffuser structures having 3, 4, 5 blades and 16mm, 20mm, 24mm blade width and 3mm, 4mm blade thickness. These variations were created to determine the effects of the number of blades, blade width and blade thickness on air flow and pressure drop performances of automobile diffusers. The impact of automobile diffusers on thermal comfort inside of the cabinet has been detected—correlations which give pressure drop and airflow angle were obtained according to analysis results. Thus, equations giving airflow direction angle and pressure drop within specific parameters were obtained without computational fluid dynamics analysis. In this way, a faster approach was provided to reach related performance values on automobile diffuser design.*
Keywords*: COMPUTATIONAL FLUID DYNAMICS, DIFFUSER, AUTOMOBILE, AIR FLOW, BLADE, PRESSURE*

1. Introduction

Nowadays, Diffuser types are used on thermal conditioning systems of automobile cabinet as circular, conventional, split types. Visuality, structural strength, soundless working, low-pressure drop and airflow directivity of automobile diffusers are important performance indicator parameters. Airflow directing to desired angle significantly affects thermal comfort inside of automobile cabinet. Diffusers having high-pressure drop value blocks to the desired airflow also influence the considerable efficiency of air conditioning. Therefore, Diffusers with high airflow directivity and low-pressure drop are needed for increasing the thermal comfort of passengers inside the automobile. One of this study aims is examining to design of attributions for diffusers having high airflow directivity ability and low-pressure drop value. Many studies are made related subject in the literature.

Somnath and Mayur investigated thermal comfort and airflow distribution in automobile cabinets and detected that directed airflow to passengers significantly affected thermal cooling load in their study [1]. Myoung Su Oh et al. studied energy recovery on automobile compartments and investigated automobile diffuser locating effects over the thermal comfort [2]. Air directing ability is critically important on diffusers for obtaining airflow distribution in automobile cabinets and increasing the thermal comfort of passengers in a cabinet. Zhang et al. analyzed airflow path and temperature in automobile cabins for with and without passenger conditions [3-4] experimentally. Nissan Hagino and Hara examined to affecting parameters of air temperature and airflow path for the purpose of understanding the thermal sensations of passengers [5]. Many studies in the literature have been seen that many investigations have been made about airflow distribution airflow direction for detection of thermal comfort. In this study, the effects of diffuser blade dimensions are examined in detail by computational fluid dynamics analysis.

2. Modelling

Automobile diffusers are produced with different dimensions, blade width, blade thickness and blade quantity by companies. Figure 1 shows a sample automobile diffuser. Analyzed parameters with computational fluid mechanics are shown in Figure 2.

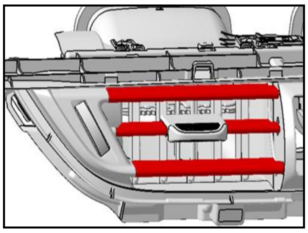

Fig. 1 *Automobile diffuser sample*

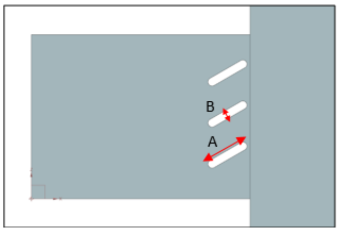

Fig. 2 *Geometric parameters*

A parameter shows blade width, B parameter shows blade thickness. Also, the effect of different blade quantities having 3, 4, and 5 blades on diffuser performance was investigated. The angle of blades with the horizontal plane is kept constant 30° for each case.

3. Governing Equations

Mathematical equations should be exhibited for solving problems and understanding physical principles. Boundary conditions and eliminate parameters must be given according to the physical structure of modeling for numerical solving of differential equations. Continuity and momentum equations used in this study are given below. Since the conditions examined in the study are turbulent flow, the RANS form of the continuity and momentum equations was used. Diffuser structure modeled with mesh structure in computational fluid mechanics was solved with the below equations.

Continuity equation indicates mass conservation during flow motion. In this study, density-dependent to the derivative of time can be eliminated due to steady-state flow. In addition, since the density is considered constant, it can be taken out from the local derivative, and in this case, the equation will be as follows.

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}+\frac{\partial \bar{w}}{\partial z}=0$$

The components of X, Y, and Z direction of momentum equation in the Cartesian coordinate system are as follows. In this study, the flow is considered a steady-state. In addition, since the density is considered constant, it can be taken out from the local derivative and in this case, the equation will be as follows.

The x-direction momentum equation

$$\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}+\bar{w}\frac{\partial \bar{u}}{\partial z}+\frac{1}{\rho}\frac{\partial \bar{P}}{\partial x}=$$

$$\left(\frac{\partial^2 \bar{u}}{\partial x^2}+\frac{\partial^2 \bar{u}}{\partial y^2}+\frac{\partial^2 \bar{u}}{\partial z^2}\right)-\frac{\partial \overline{(u')^2}}{\partial x}-\frac{\partial \overline{(u'v')}}{\partial y}-\frac{\partial \overline{(u'w')}}{\partial z}$$

The y-direction momentum equation

$$\bar{u}\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial \bar{v}}{\partial y}+\bar{w}\frac{\partial \bar{v}}{\partial z}+\frac{1}{\rho}\frac{\partial \bar{P}}{\partial y}=$$

$$\nu\left(\frac{\partial^2 \bar{v}}{\partial x^2}+\frac{\partial^2 \bar{v}}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)-\frac{\partial \overline{(u'v')}}{\partial x}-\frac{\partial \overline{(v')^2}}{\partial y}-\frac{\partial \overline{(v'w')}}{\partial z}$$

The z-direction momentum equation

$$\bar{u}\frac{\partial \bar{w}}{\partial x}+\bar{v}\frac{\partial \bar{w}}{\partial y}+\bar{w}\frac{\partial \bar{w}}{\partial z}+\frac{1}{\rho}\frac{\partial \bar{P}}{\partial w}=$$

$$v\left(\frac{\partial^2 \bar{w}}{\partial x^2}+\frac{\partial^2 \bar{w}}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-\frac{\partial \overline{(u'w')}}{\partial x}-\frac{\partial \overline{(v'w')}}{\partial y}-\frac{\partial \overline{(w')^2}}{\partial z}+g_z$$

4. Numerical Results

In this study, Pressure drop and airflow direction angle values were detected by using 3, 4 and 5 blade quantities with 3 mm blade thickness. Computational fluid mechanics result of pressure and velocity contours were shown in figures as below.

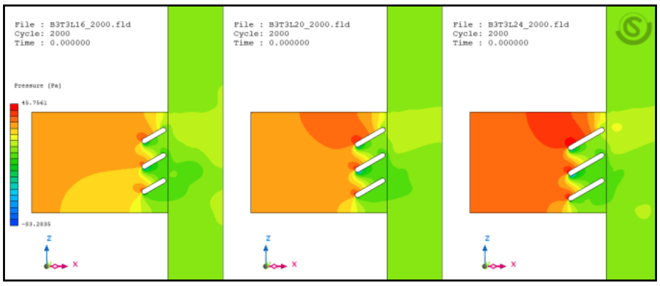

Fig. 3 *Pressure drop contour of 3 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

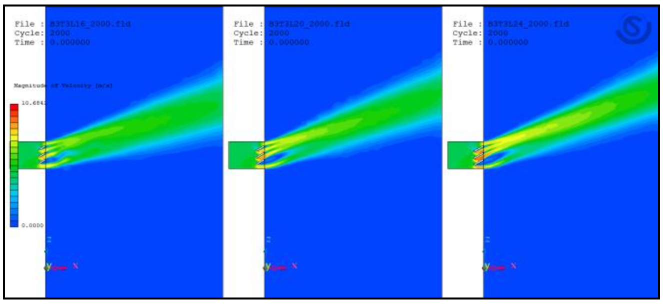

Fig. 4 *Velocity contour of 3 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

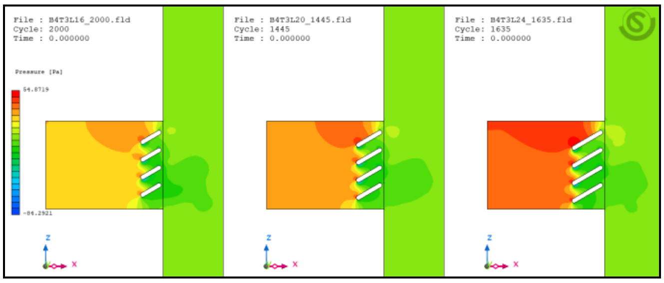

Fig. 5 *Pressure drop contour of 4 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

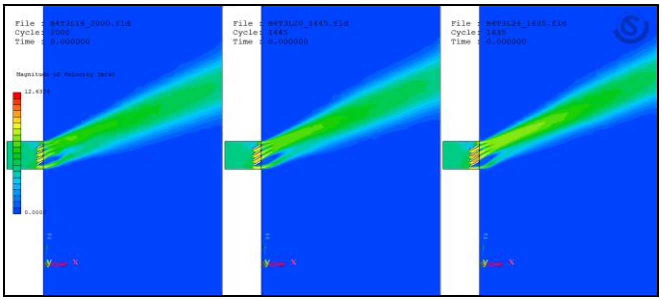

Fig. 6 *Velocity contour of 4 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

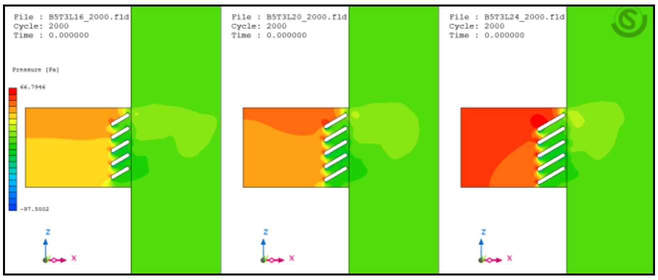

Fig. 7 *Pressure drop contour of 5 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

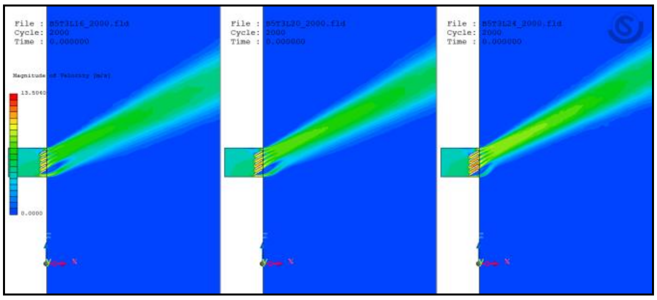

Fig. 8 *Velocity contour of 5 blades and 3 mm blade thickness (16 mm, 20 mm, 24 mm, blade width, respectively)*

The effect of blade thickness on airflow directing ability and pressure drop performances in automobile diffusers has been investigated, and contours that are the output of computational fluid mechanics analysis are given in the figures below.

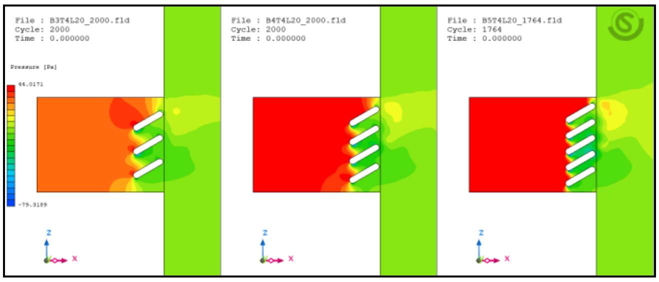

Fig. 9 *Pressure drop contour of 3, 4, 5 blades and 4 mm blade thickness (20 mm blade width)*

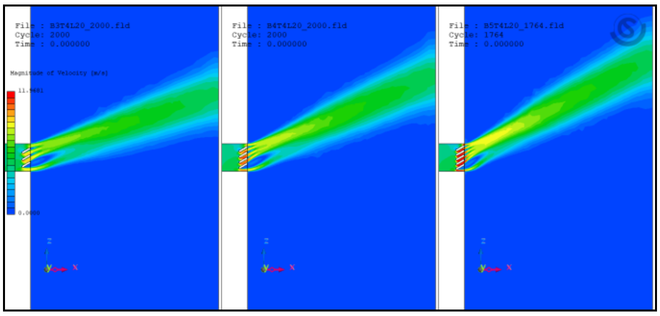

Fig. 10 *Velocity contour of 3, 4, 5 blades and 4 mm blade thickness (20 mm blade width)*

Pressure drop and airflow direction angle obtained from computational fluid dynamics analysis were listed as below Table 1 according to blade quantity, blade thickness, blade width.

Table 1: *Numerical pressure drop and airflow angle values for different blade thickness, quantity, and width*

Blade Quantity	Blade Thickness	Blade Width	Pressure Drop (Pa)	Air Flow Angle (°)
3	3 mm	16 mm	20,7 Pa	16°
3	3 mm	20 mm	25,5 Pa	19°
3	3 mm	24 mm	31,3 Pa	21°
4	3 mm	16 mm	26,4 Pa	21°
4	3 mm	20 mm	32,5 Pa	23°
4	3 mm	24 mm	40,2 Pa	24°
5	3 mm	16 mm	33,9 Pa	25°
5	3 mm	20 mm	41,6 Pa	27°
5	3 mm	24 mm	52,1 Pa	28°
3	4 mm	20 mm	29,7 Pa	19°
4	4 mm	20 mm	41,5 Pa	23°
5	4 mm	20 mm	59,2 Pa	27°

Correlations giving pressure drop and airflow direction were created according to obtained results. Thus, equations giving pressure drop and airflow angle-dependent to blade quantity and blade width were obtained for automobile diffusers.

$$\boldsymbol{\Delta P} = (0{,}3046x^2 + 0{,}186x + 5{,}76).\,e^{(0{,}001x + 0{,}0487)y}$$

$$\Delta P = Pressure\ drop \quad x = Blade\ quantity \quad y = Blade\ width$$

$$3 \le x \le 5 \qquad 16 \le y \le 24$$

$$\boldsymbol{F°} = (2{,}461x^2 - 22{,}149x + 56{,}67).\ln(y) + (-7{,}3303x^2 + 69{,}972x - 162{,}17)$$

$$F° = Air\,flow\,angle \quad x = Blade\,quantity \quad y = Blade\,width$$

$$3 \le x \le 5 \qquad 16 \le y \le 24$$

5. Conclusion

In this paper, automobile diffuser airflow directivity and pressure drop performances are presented. Context of this study results, some approaches were obtained for automobile diffuser performance improvement. According to the computational fluid dynamics analysis, it has been observed that as the blade width is increased, the airflow directing ability also increases, but this situation increases the pressure drop. Another of the findings obtained in the studies is that the airflow directing ability of automobile diffusers increases when the number of blades is increased, but in this case, pressure drop also increases and it affects diffuser performance in a negative way. When these two situations are compared, it has been determined that increasing the number of blades in automobile diffusers increases the pressure drop less than increasing the blade width and affects the airflow directing ability more positively. Increasing the number of blades is more efficient than increasing the blade width in order to achieve the ability to direct airflow during the design of automobile diffusers. Increasing the fin thickness in the diffusers does not affect the airflow directing ability and increases pressure drop and negatively affects diffuser performance was detected on studies. In line with the studies, two correlations giving the angle of directing the airflow and the pressure drop were obtained. Thus, performance values can be obtained according to the desired number of blades, and blade width were determined without the need for computational fluid dynamics analysis.

6. References

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