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# CFD analysis of an anemometric sensor design for air flow measurement in a heat exchanger

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**Abstract.** This paper focuses on the issue of flow measurement in automotive heat exchangers. The measurement is complicated due to the limited space in the heat exchanger area and the non-uniform velocity profile. Therefore, only some measuring techniques can be used, which must be adapted to the specific conditions. The paper presents the initial stages of the development of a sensor for measuring the flow in a heat exchanger. These are CFD simulations used to determine the nature of the flow around the sensor and verify its effect on the flow field in its surrounding and on the entire heat exchanger. The results of these initial simulations are presented and discussed.

## 1 Introduction

Due to the limited efficiency of passenger car drives and other systems, residual heat is generated during their operation. It must be dissipated to the surrounding environment. This is solved using heat exchangers, usually a set of exchangers according to the characteristics of a particular car. The heat exchangers are normally located in the front of the car, where it is easier to ensure their proper function. This is a sufficient flow of air around their heat exchange surfaces. It is influenced not only by the heat exchangers themselves, but also by the flow around the car and inside the engine compartment, the shapes of the grilles, the fans and other elements. Experimental measurements directly on the exchangers are necessary to verify their correct function [1]. The measurement usually takes place directly at or in the relevant heat exchanger. However, these measurements are quite complicated because there is very limited space for the installation of measuring probes in the area of exchangers [2].

Only a few methods can be used for direct measurement of the air flow integral value [3]. One of them is hot-wire (-film) anemometry [4, 5]. Some previous work focused on the use of hot wire anemometers with traversing probes along the exchanger surface pointed out, that this measurement is in fact impossible in the engine compartment and it has significant measurement error due to considerable inhomogeneity of the flow behind the exchanger. Both of these problems should be eliminated by installing hot-wire (-film) sensors in the exchanger. The development presented in this paper was therefore focused on installing a sufficient number of sensors into the heat exchanger to ensure the accuracy of direct measurement of the total air flow. It is thus an intrusive method with the necessary removal of fins with louvres between the channels with the cooled medium.

The presented work focuses on the initial stage of the development of hot film sensors for this type of measurement. This stage involved determining the concept of the sensor from the point of view of the sensing element and the electronics. Based on this concept, it was possible to determine the expected dimensions of the sensor and design it. The sensor model was then implemented in a selected type of heat exchanger and CFD simulations [6] were performed to optimize its design and verify its properties and impact on the modified exchanger.

## 2 Sensor design, models

As mentioned, the sensor model was based on the concept of the hot film element and electronics. A hot film was chosen because the company has thin layer sensors of its own development. The dimensions of the hot film plate were designed 7x9 mm. A suitable structure of the hot film was designed on the surface so that the film reached resistances suitable for the current regulator, which ensures its heating. The hot film plate is placed directly on the printed circuit board with current regulator and electronics for measurement and communication.

The dimensions of the printed circuit board were set at 20x20 mm with a thickness of 3 mm. These dimensions already include the final surface treatment of the sensor, i.e. coating the board by a protective and insulating housing. The plate with the hot film element protrudes 0.3 mm above the surface of the encapsulated printed circuit board. Thin side plates have been designed to secure the position of the sensor between the channels. These can be modified according to the

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specific type of exchanger without changing the sensor itself. The effect of the length of these side plates was assessed during the initial CFD simulations. Based on the results, their length was determined to be the same as the depth of the sensor, i.e. 20 mm. The model of the resulting sensor design is shown in Figure 1.

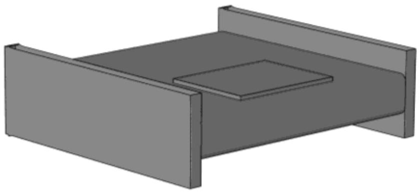

**Fig. 1.** Model of the hot film sensor.

A detailed model of a part of the selected heat exchanger was prepared to assess the influence of the designed sensor on the change of flow through the exchanger at the place of its installation and the change of the pressure loss of the exchanger. A segment of size 32.2 x 23.25 mm (depth of the exchanger 26 mm) was selected from the exchanger, for which detailed models without and with implemented hot film sensor were prepared. Both segment models are shown in Figure 2.

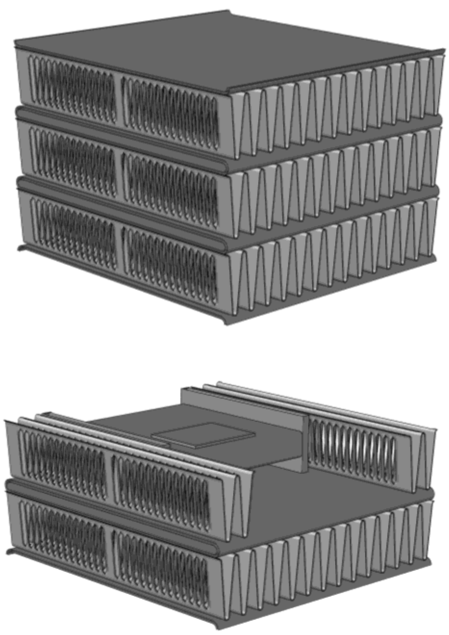

**Fig. 2.** Heat exchanger segment models: without sensor and with hot film sensor implemented (part of the segment with a view of the sensor location).

The segments were placed in the overall model, which includes the input and especially the output part to affect the flow behind the segments. Symmetries and periodicities were applied to the walls to reduce the influence of boundary conditions. Normal velocity was defined at the inlet and atmospheric pressure at the outlet. The computational mesh consists of 9.3 million polyhedral cells. The overall model is shown in Figure 3.

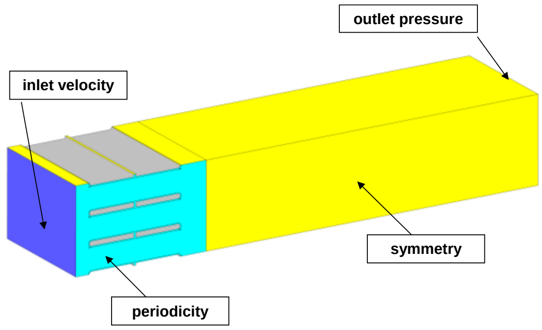


**Fig. 3.** The overall model with boundary conditions.

## 3 CFD simulations - segments

CFD simulations on models with heat exchanger segments were performed in the ANSYS Fluent 2021 R1 program [7]. The flow was considered incompressible (air) and turbulent – k-ω SST turbulence model [8]. Inlet velocities were considered in the range of 2.5 to 10 m/s. The outlet pressure was defined as atmospheric.

Selected variants of the model were also solved with heat transfer, when a constant temperature of 80 degrees Celsius was set on the surface of the water channels.

The simulations were not solved only for the mentioned model geometries, the analyses also included variants for assessing the location of the hot film sensor between channels (front, rear), sensor inclination (mounting error) and hot film element plate position (longitudinal and transverse orientation).

The following results are for the indicated model geometries and without heat transfer only.

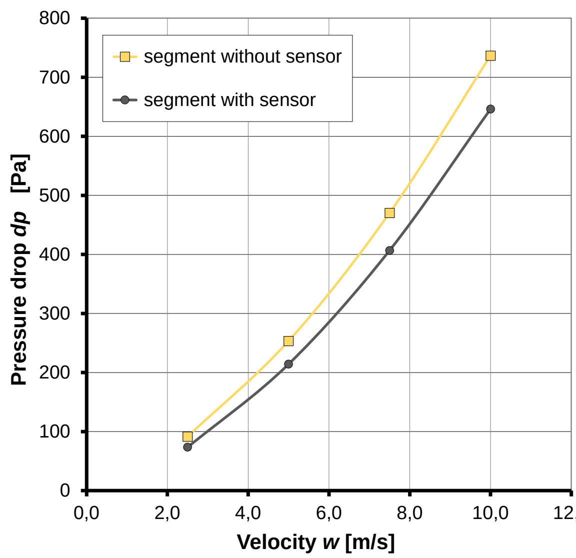


**Fig. 4.** Pressure drop of the segment models with and without the sensors.

An important result of CFD simulations was the finding of the difference in segment pressure loss. The graph in Figure 4 shows that the segment with the sensor has a lower pressure drop, the difference compared to the segment without the sensor is about 20 % depending on the conditions.

The following figure 5 shows flow lines in the model's segments coloured by the velocity.

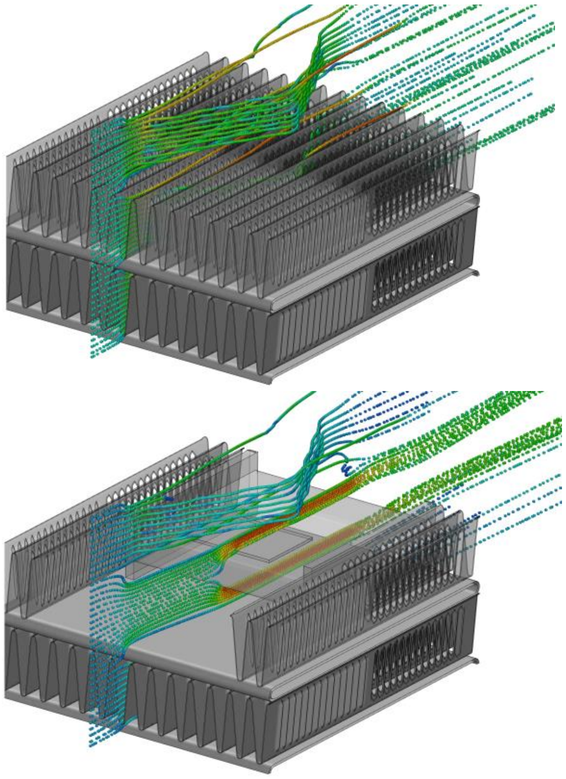

**Fig. 5.** Flow lines coloured by velocity: segment without sensor at the top, with sensor at the bottom.

The results found on both segment models are important, but do not comprise the overall impact of sensor installation on the heat exchanger. However, the application of the used methodology to the whole exchanger is not possible in principle. The size of the computational task i.e. the number of computational elements would reach extreme values.

## 4 CFD simulations – porous zones

To determine the effect of sensors installation on the whole exchanger, a simplified model with use of porous zones for different parts of the exchanger was prepared. The model was again in version without and with sensors. Based on the results of both model segments listed in the previous chapter, the parameters of two types of porous zones were determined - the heat exchanger part without the sensor and the heat exchanger part with the installed sensor.

To maintain the highest similarity of this model to the real exchanger, water channels were preserved and the porous zones replace only the fins and louvres volume.

Figure 6 shows the segment with porous zones with the sensor. The segment without the sensor was prepared and solved in a similar way. With the help of these sub models, the whole model of the exchanger was assembled. A total of 70 sensors were considered for optimal coverage of the area of the heat exchanger. In this case, the individual sensors cover the same area and the integral determination of the air flow is thus simple and correct.

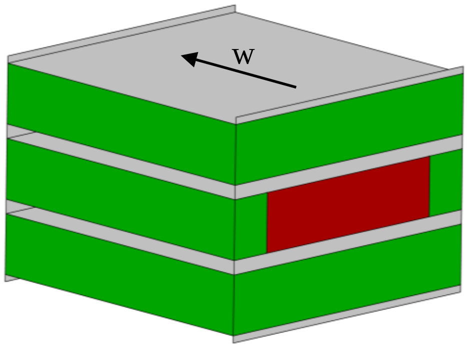


**Fig. 6.** Segment model with fin and louvres and sensor area simplified by porous zone.

A schematic view of the distribution of the sensors over the heat exchanger surface is shown in Figure 7.

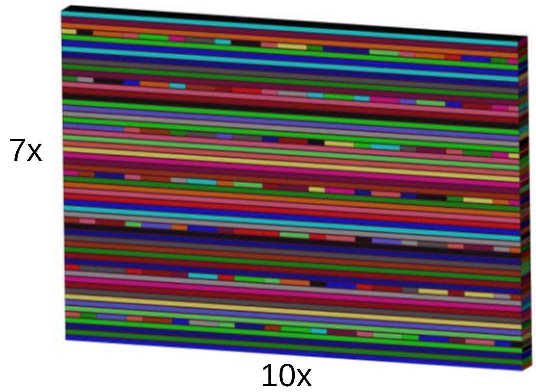


**Fig. 7.** Geometry of the overall porous heat exchanger model with sensors in a 10x7 matrix.

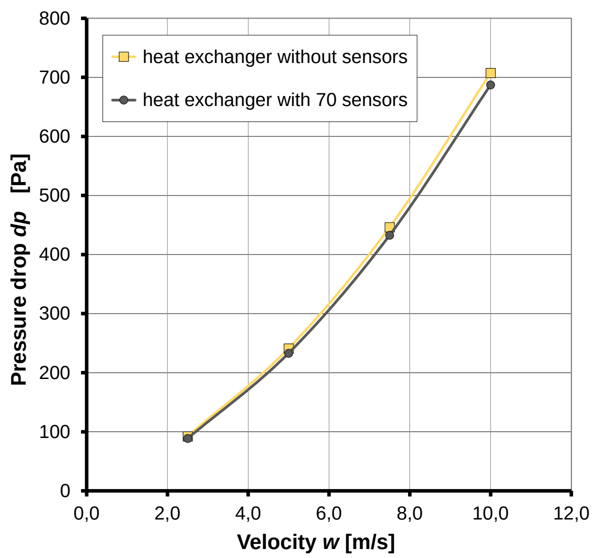


**Fig. 8.** Pressure drop of the entire heat exchanger models (porous zones) with and without the sensors.

CFD numerical simulations for the whole exchanger model were performed under the same conditions as the simulations for the segments. Heat transfer was not considered at all for these model variants. In addition to a detailed analysis of the velocity field in the heat exchanger area, the basic result was again the pressure drop of the heat exchanger with and without sensors.

The comparison is shown in the graph in Figure 8. The result shows that when the entire area of the exchanger is considered, the influence of the sensors is very small. The pressure loss difference is 3.3 %. Given the idealized mounting of sensors in computational models, it can be expected that the difference will be probably even lower in real design. The velocity field in the cross-section of the exchanger is shown in Figure 9. The figure shows higher velocities behind the exchanger in the area of the sensors, which is still visible far beyond the exchanger.

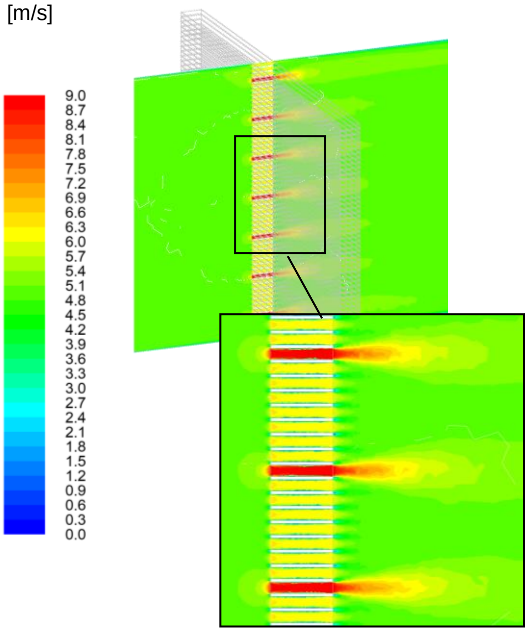


**Fig. 9.** Velocity contours in vertical section through the exchanger in the axis of the sensor column.

## 5 Conclusions

The previous chapters gave a brief description of the initial stages of the development of a hot film-based sensor for measuring the total air flow through automotive heat exchangers. Based on the concept of the hot film element itself and the necessary electronic part, a sensor model was developed. It was implemented in the exchanger segment model and subjected to computational analyses. The aim was to find a suitable shape and location of the sensor in the exchanger and to verify the sensitivity of future measurements to the design of the sensor and the errors of its mounting. After verifying the design on a small segment, a model of the entire exchanger was prepared. Due to the multiple increments of the model, it was necessary to use simplification, fins and louvres are modelled as porous zones. The results show a small deviation (3.3 %) of the pressure loss of the exchanger with installed sensors from the exchanger itself. At the same time the results show an acceleration of the flow in the slots with the sensor, which is also significant in the area behind the exchanger. The next step in the analysis is to supplement the model with fan holder and fans (Sahara). The calculations should lead to an evaluation of the determined higher velocities behind the sensors. At the same time, various operating conditions will be analysed, including the influence of fans.

## Acknowledgement

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