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THE EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE COANDA EFFECT AT THE FLAT PLATE

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Abstract

The Coanda effect is the tendency of a fluid jet coming from the slot, to be attracted to a nearby surface. In ventilation issues, the aforementioned effect is considered mainly as an undesirable phenomenon, which may cause an unsuitable air distribution, the lack of thermal comfort or even drafts. Our interest in the use of the hysteresis of the Coanda effect in improving the effectiveness of mixing ventilation systems required also the initial investigations of the effect itself. Numerical studies to determine the critical separation angle α, with the help of the FloVent software, confirm laboratory results.

Key words: the Coanda effect, CFD analysis

1. INTRODUCTION

To characterize the air movement in rooms two flow patterns are usually used: the displacement and entrainment flow [1]. The first case assumes, that no air mixing in a room will occur, whereas, in the second case of entrainment flow, the complete mixing is desired. Unfortunately, the uniform mixing can be distorted by the Coanda effect. The attaching of the stream coming from the slot to the plate or convex surface may change the designed air distribution in the ventilated room or even cause a draft [2]. Because of that, the Coanda effect is mostly undesirable in ventilation issues. What is more, stagnant surroundings are one of the main reasons for high concentration levels of contaminant, if sources are present in the involved area [3].

According to the U.S. Environmental Protection Agency, the concentration of air pollutants inside the building reaches a level of 2 to 5 times higher than in outdoor air. This information is particularly worrying because the cited source also indicates that currently, people spend about 90% of their time in buildings, of which approximately 65% of them are the homes. To inefficient ventilation system and the low quality of ventilation air, are exposed those, who are spending the most time at home: children, pregnant women, elderly and sick people. In extreme cases, we can have to do with the so-called “sick building syndrome”, where people suffer from headache, fatigue, irritation of eyes, nose and throat, and difficulty concentration. We can not also ignore the purely economic impact of inefficient ventilation system: fungus and mildew that occur most often in the corners of rooms, swelling of wood floors and furniture, the gradual destruction of the building construction, etc. [4]

These conditions clearly indicate the need to work on improving the effectiveness of comfort ventilation systems, which typically are based on the principle of air mixing.

The aim of our study was to better understand and use the phenomenon of the hysteresis of the Coanda effect. All given below experimental investigations were performed at University of Warmia and Mazury in Olsztyn, which were partly supported by the research projects PB Nr 512 030 31/3280 “Use of the hysteresis of the Coanda effect to increase the efficiency of the mixing ventilation”. The complete understanding of the hysteresis phenomenon can help to control it and exploit its potential, by using the occurring instability in air stream. We assume, that application of the time dependent, harmonic pressure in the nozzle, can cause a wavy motion of air downstream, which will result in a much better efficiency of air mixing [5]. Expected air distribution illustrate the Figure 1.

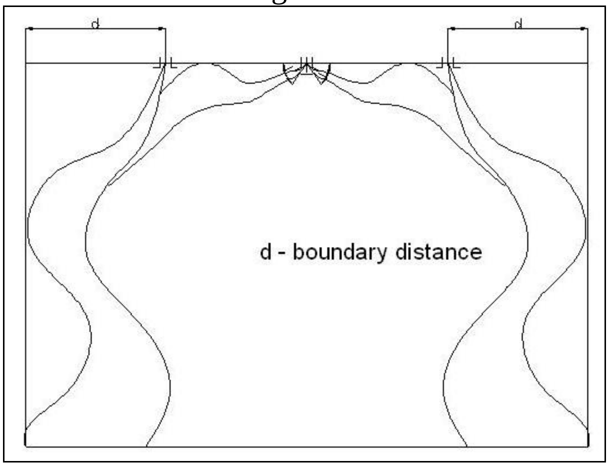

Fig. 1: Visualization of air mixing improvement for ventilation, by using the hysteresis of the Coanda effect [5].

The results presented in this article, aimed also at numerical simulation of the Coanda effect, so that in future it will be able to create a numerical model of the system with a new kind of diffuser, based on the phenomenon of hysteresis of the Coanda effect.

1.1. HYSTERESIS OF THE COANDA EFFECT

The starting point of our study was the Newman's investigations [6], where the hysteresis phenomenon of the Coanda effect was described probably for the first time. In his research a measuring system was used, where one lip of the slot of width b was extended as a straight wall of length l. This wall was inclined at an angle α to the axis of slot. It was found that a certain range of α angle exists, where two flow regimes are possible for a given geometry. One limit of this angle range is determined as a free jet flow and the other, reattachment to the wall. The free jet and reattachment depends on the direction of the motion of the flat plate.

2. EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

2.1. EXPERIMENTAL RIG

The experimental investigations were made in the lab of the Chair of Environmental Engineering at the University of Warmia and Mazury in Olsztyn, in the special test chamber of dimensions 3850x2255x2009 mm. Thanks to that, the outside air motion did not have impact on the results. The air on the test stand was derived by an air intake (diameter 400mm). The air intake had a throttling orifice, thanks to that we were able to change the volume of the air approaching the nozzle. On the test stand there was a fan, which was connected a electrical engine. On the pressure side of the fan the Witoszynski nozzle was applied. The air stream was coming from the two-dimensional Witoszynski nozzle of dimensions hxb (Fig. 2), where the height of the nozzle was constant $h = 0,6m$ and the width b can be varied appropriately ($b = 5,10,20mm$) for investigation of critical angles range for hysteresis phenomena. The plate of length $l = 1,0m$ was placed at the one edge of the Witoszynski nozzle and the plate could be turned in the angle range $\alpha = 0 \div 90°$. Thanks to that it was able to generate a flat 2-D air stream, which could flow as a free jet or detached to the plate according to the angle between plate and the nozzle axis. The plate could be manually turned and the angle set continuous with the accuracy of 1°. The pressure on the plate surface was measured in 48 point evenly distributed at a central line of the plate The measurements of the separation bubble length, in the case of the detached flow, was made by evenly distributed thin threads placed on the plate.

The air velocity from the nozzle was determined as the ratio of air volume by the nozzle cross-section area, or by the pressure difference measurement at the nozzle or by means hot-wire system. The velocity range used during the investigation was 5 m/s to 32 m/s, so the Reynolds numbers range based on the nozzle's width was Re= 7 000 till almost 40 000. [7]

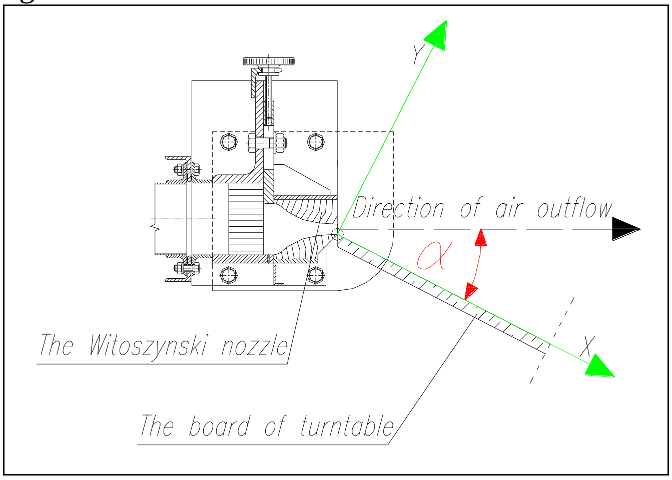

Fig. 2: Experimental rig with the Witoszyński nozzle and plate (board of turntable) and the coordinates system with adopted local reference system.

2.2. NUMERICAL CODE

Laboratory tests were reconstructed by the use of Computational Fluid Dynamics (CFD) methods, in particular of FloVent software by Mentor Graphics. Figure 3 illustrates the numerical model of the test stand for FloVent investigations. Dark blue color lines represents the plexiglas test stand walls. The green lines reflect range of test stand. The turntable plate, which extends one lip of the nozzle is marked in red. Blocks marked purple, are the area density of the measuring grid, under which were subjected to analysis of test parameters on the wall jet (Fig. 4). The FloVent's local reference system is also marked at the Figure 4.

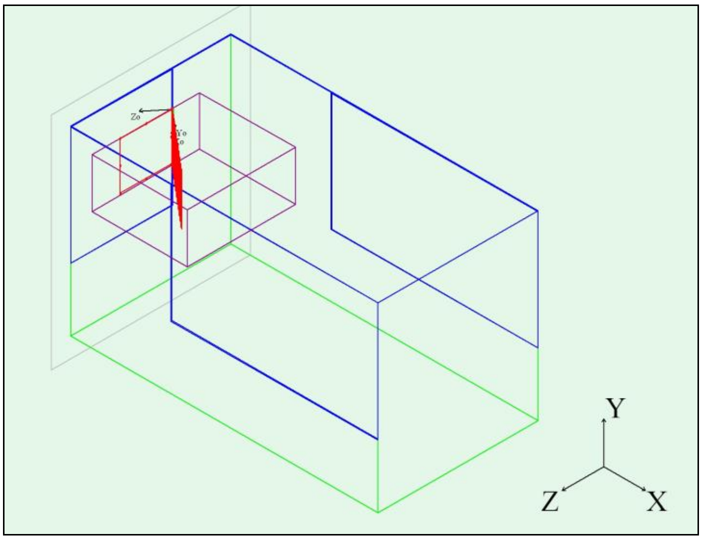

Fig. 3: Scheme of test stand in Flovent software.

During the simulations a grid system with about 3 400 000 cells was used. In the area where the occurrence of the Coanda phenomenon and jet properties were analyzed, the single grid cell size was X=5mm, Y=20mm, Z=5mm (directions marked according to the scheme adopted in the Flovent). That area dimensions were X=1,20m; Y=0,62m; Z=1;00m. The Figure 4 illustrates the grid system.

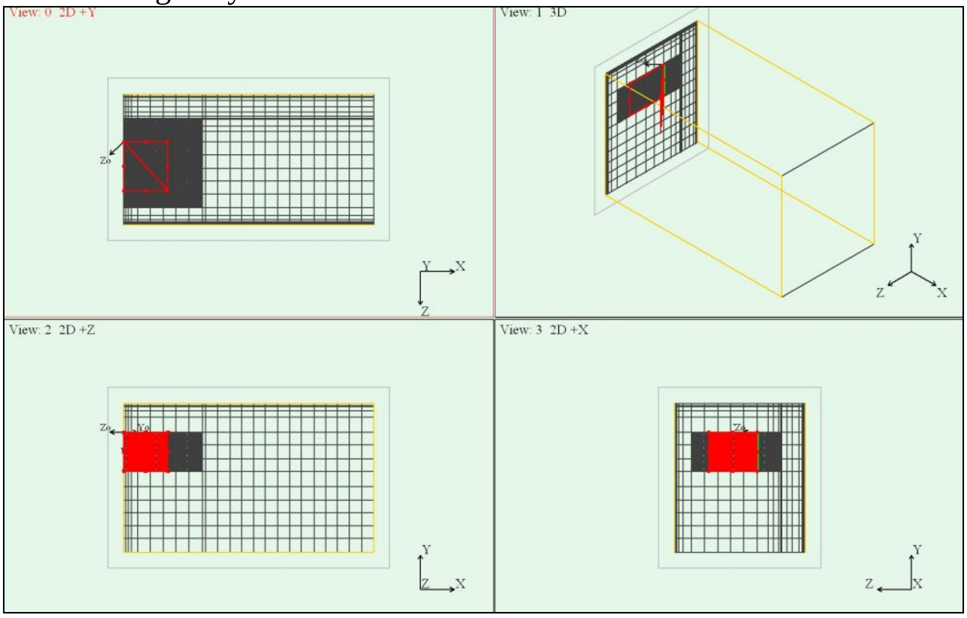

Fig. 4: The grid system used in the Coanda effect simulations in FloVent software.

The Flovent code has three possibilities to model the turbulence: LVEL K-Epsilon, Capped LVEL and LVEL Algebraic. According to the technical recommendation, during our simulations the LVEL K-Epsilon turbulence model was used, which actually corresponds to the ordinary k-ε model which is applied quite often also in nowadays simulations

3 RESULTS

Next, both the experimental and numerical results are presented.

3.1. EXPERIMENTAL RESULTS.

3.1.1. HYSTERESIS

First, the hysteresis phenomenon i.e. the separation and detached flow angles of Coanda effect are given in Fig. 5 for high Reynolds numbers. This results are very similar to results given by Newman.

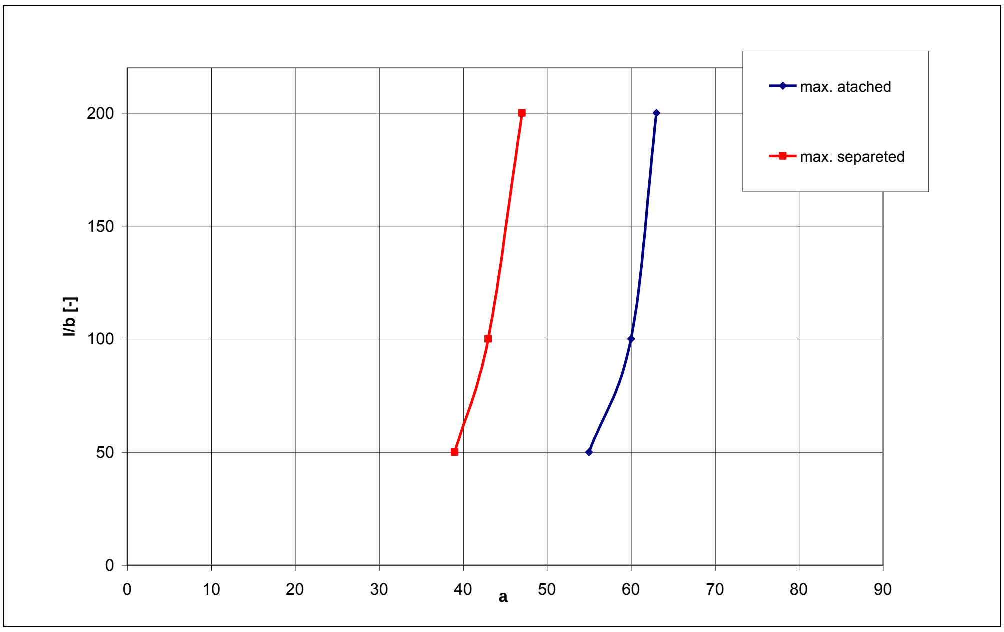

Fig. 5: Experimentally determined regimes of hysteresis of Coanda effect at high Re.

In the conducted numerical simulations, we wanted to confirm the results obtained experimentally. With use of FloVent software by Mentor Graphics the range of maximal separation angle was confirmed. Unfortunately, in conditions of steady state numerical investigations, representation of the hysteresis of the Coanda effect phenomenon was impossible. The value of the critical angle α, when the air jet was reattached has not been verified.

Determinant exceeded the critical separation angle α, was to obtain 0 Pa pressure values on the turntable. An example of the pressure measuring results on the turntable in the direction of critical separation angle α represents fig. 6.

3.1.2. PRESSURE DISTRIBUTION ON THE PLATE

In Fig. 6 the pressure distribution measured along the plate are given for different angle α between on the

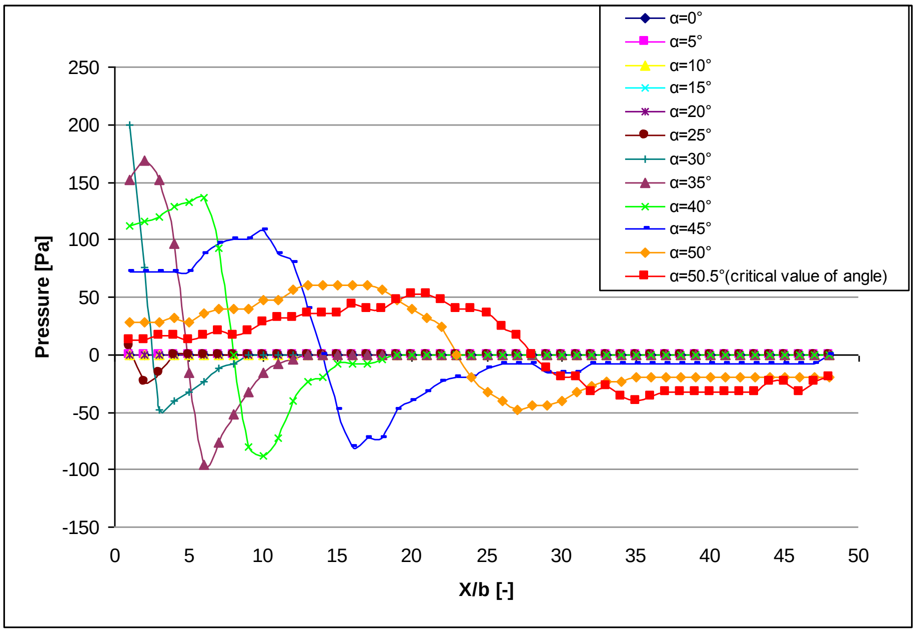

Fig. 6: Pressure on the plate for different angle α, Re=42 240.

The maximum pressure value is observed in a short area directly behind the diffuser (nozzle), are for an angle $\alpha = 30°$. With the angle increase, there was observed a decrease of pressure value and extended the area until complete disappearance, after critical value of angle was reached. reaching.

3.1.3. WALL JET

The wall jet examinations started from a comparison of experimental and numerical results with the theoretical values given first by Goertler, and also in Newman.

Below, there is some exemplary analysis mean velocity profiles for selected X direction stations during wall jet examination. Analytical calculations were done according to the formula [6] for the angle case $\alpha = 0°$:

$$u = u_m \operatorname{sec} h^2 \left\{ 0{,}88 \left(\frac{y - y_m}{y_{m/2} - y_m} \right) \right\} \tag{1}$$

where:

u – mean velocity parallel to the jet axis,

u_m - maximum value of u at given station,

y - distance measured perpendicular from the wall,

y_m - value of y at which u is maximum for the wall jet,

$y_{m/2}$ - larger value of y for which $u = \frac{1}{2} u_m$.

The results convergence confirm the correctness of our investigations. Figures 7 and 8 represents selected results of experimental, analytical and numerical analyze of mean velocity profiles for selected X direction, for the nozzle's width $b = 20mm$.

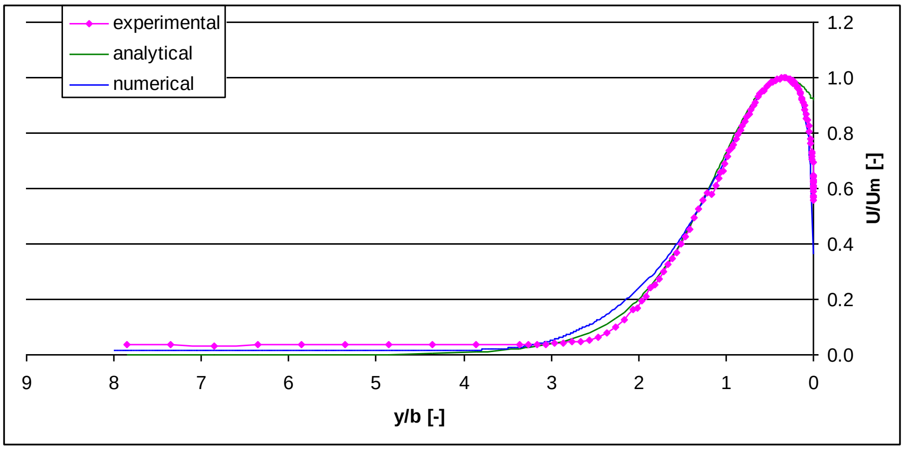

Fig. 7: Dimensionless analyze velocity u/u_m profiles for experimental, analytical and numerical results; Re=42 558; $x = 0,20m$.

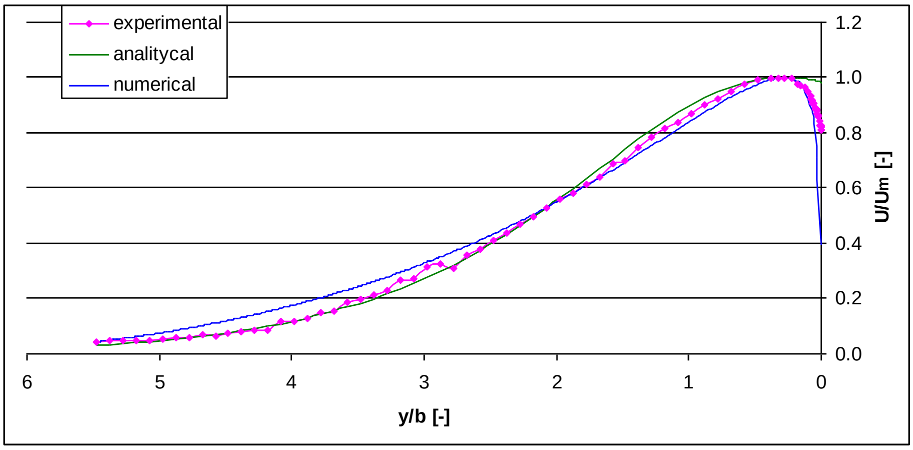

Fig. 8: Dimensionless analyze velocity u/u_m profiles for experimental, analytical and numerical results; Re=42 558; $x = 0,50m$.

3.2. NUMERICAL SIMULATIONS OF COANDA EFFECT AND HYSTERESIS

Numerical investigation of the critical angle α, when the air jet was separated, was carried out gradually. Starting point was an indication, that during experimental investigations, depending on the Reynolds number, the α angle value was changing. For example, when $\mathrm{Re} = 11450$ the critical separation angle was $\alpha = 55°$, while $\mathrm{Re} = 42240$ the critical separation angle was $\alpha = 51°$. However, irrespective of the critical separation angle α, for the range $0 \div 45°$ the air jet always should be attached to the plate. Below there are , the results for two different Reynolds numbers ($\mathrm{Re} = 11450; \mathrm{Re} = 42240$), which have confirmed those observations (Figs. 9, 10 and 11).

Numerically determined the critical separation angle is slightly lower (about 3º), than experimental one (Figs. 12 and 13); for $\mathrm{Re} = 11450$ the critical separation angle $\alpha = 52°$, for $\mathrm{Re} = 42240$ the critical separation angle $\alpha = 48°$.

After exceeding the critical angle value, the free jet was observed (Fig. 14).

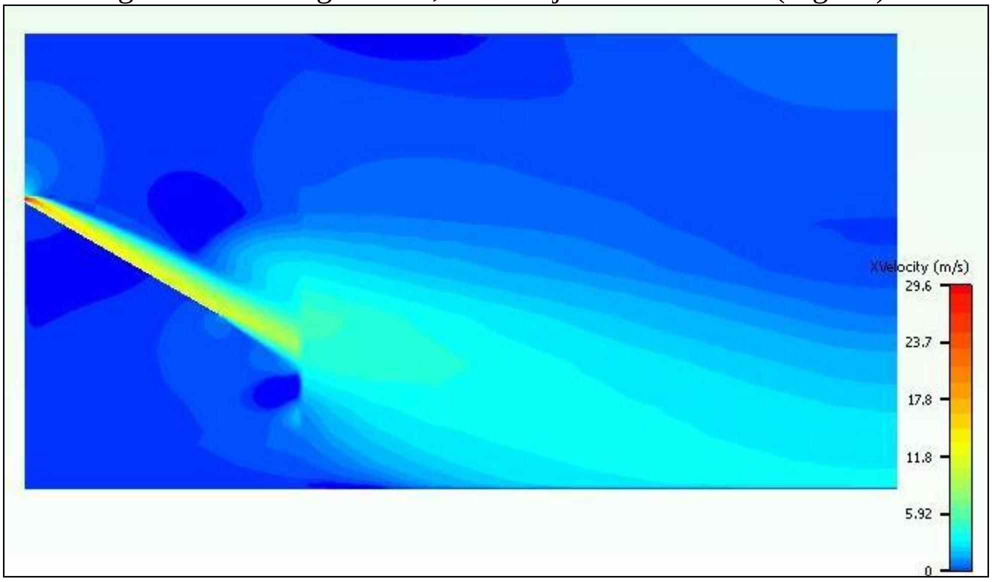

Fig. 9: Simulation of the Coanda effect, angle $\alpha = 30°$; $\mathrm{Re} = 42240$.

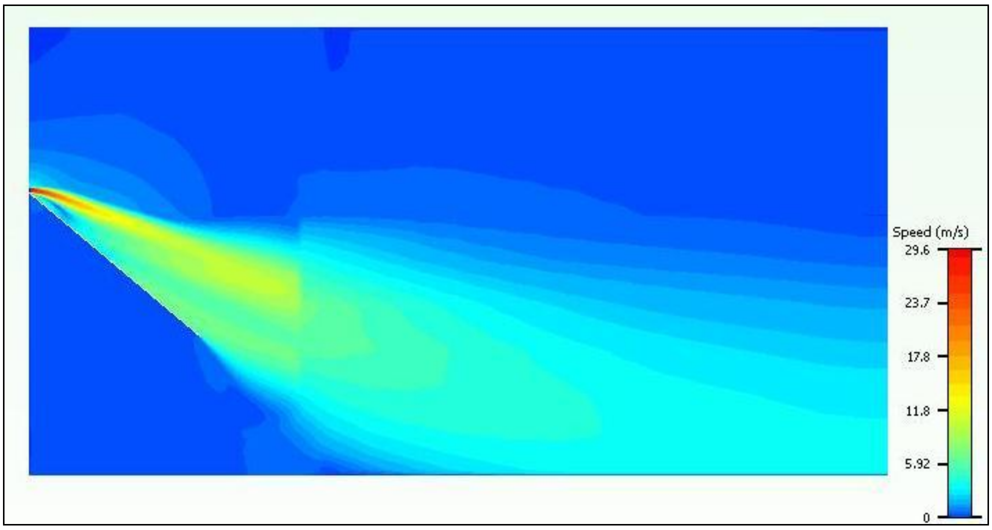

Fig. 10: Simulation of the Coanda effect, angle $\alpha = 40°$; $\mathrm{Re} = 42240$.

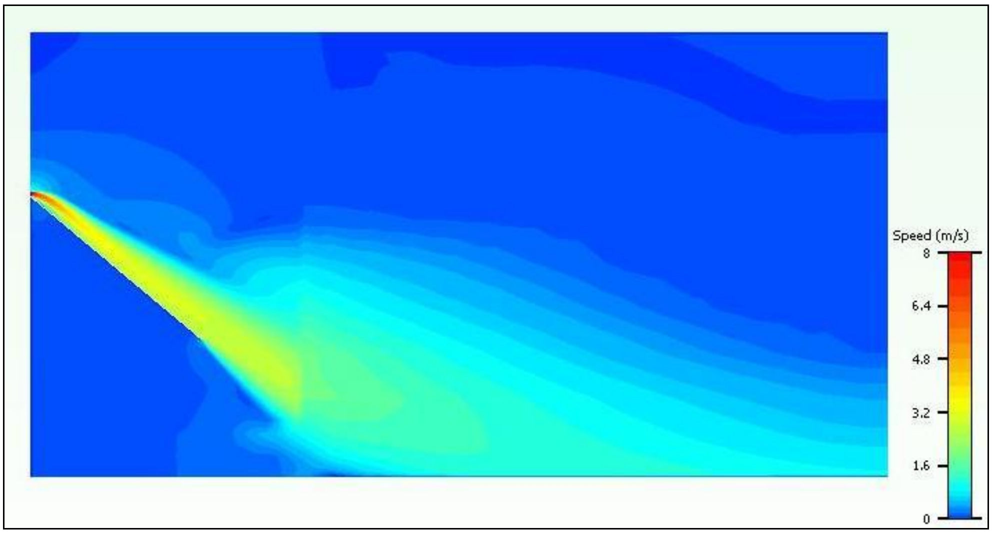

Fig. 11: Simulation of the Coanda effect, angle $\alpha = 40°$; $\mathrm{Re} = 11450$.

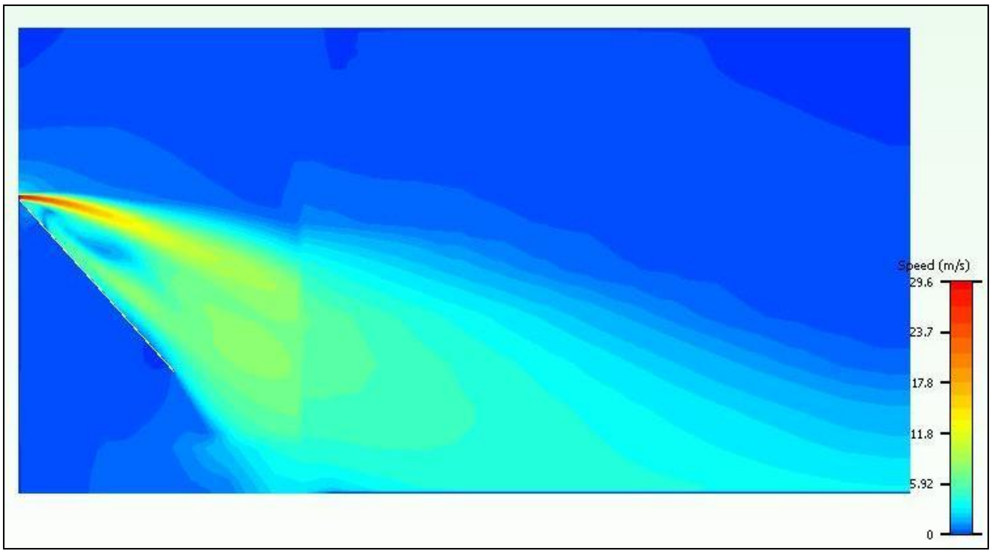

Fig. 12: Simulation of the Coanda effect – critical separation angle $\alpha = 48°$; $\mathrm{Re} = 42240$.

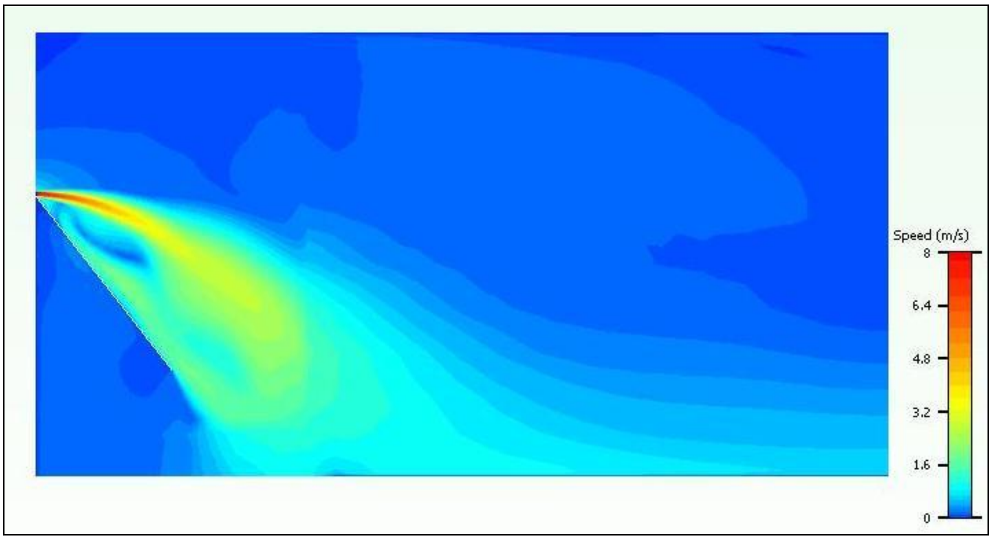

Fig. 13: Simulation of the Coanda effect – critical separation angle $\alpha = 52°$; $\mathrm{Re} = 11450$.

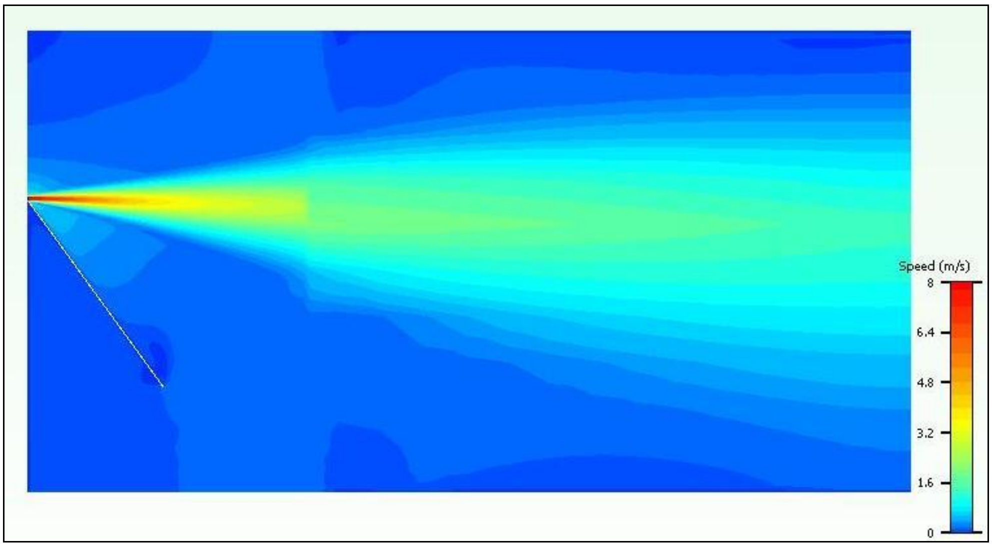

Fig. 14: Simulation of the Coanda effect – free jet, angle $\alpha = 54°$; $\mathrm{Re} = 11450$.

3.2.1. POSITION OF REATTACHMENT

The obtained numerical results, confirmed experimental investigations of the position of reattachment x_r for various α (Fig. 15).

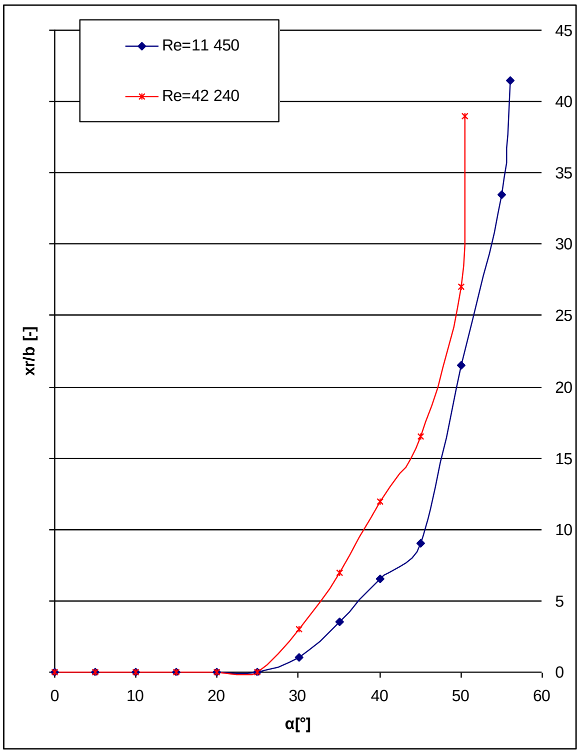

Fig. 15: The position of reattachment x_r for various α.

For the same angle value, air jet with smaller Reynolds number, was characterized by smaller value of reattachment x_r position. Numerical representation of this dependence was on the figures 10 and 11.

4. CONCLUSIONS

The results obtained with the use of FloVent confirmed experimental investigations related to the Coanda effect. Particularly, the value of the critical angle when the separation of jet from the flat plate took place was confirmed. Hence, the opportunity was gained not only to examine the properties of jet (velocity and turbulence level) with the use of CFD tools, but also the range of occurrence of the Coanda effect and its hysteresis.

However, the steady state CFD simulations, bring also some limitations. During the experiments the plate was moved and the instantaneous behaviour of the hysteresis could be observed. The unsteady numerical simualtions are not possible also by more developed methods of calculations.

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