COMETa 2022
6th INTERNATIONAL SCIENTIFIC CONFERENCE

17th - 19th November 2022
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

DILLEMA ABOUT INFLUENCE OF SPLITTER VANES ON HYDRAULIC CHARACTERISTIC AT RECTANGULAR RADIUS ELBOW

Valentino Stojkovski[1], Marija Lazarevikj[2], Viktor Iliev[3]

Abstract: Elbows are fittings in rectangular ducts which change the direction of the air stream without changing the air quantity or average velocity. When there is a change in direction in a duct then duct walls must absorb the sudden impact of the air in order to redirect the airflow to the desired direction. Splitter vanes assist the airflow in making a smoother and more gradual change in direction, thus transferring less impact and less force to the duct walls. While the splitter vane surfaces do add a small amount of friction, the amount of energy loss due to friction from the vanes is very little compared to the energy loss resulting from the airflow taking an abrupt change in direction. Splitter vanes in rectangular elbow are perhaps one of the greatest sources of conflict between the state that splitter vanes can cause the ductwork to become less efficient by increasing the pressure drop in the system and contrary that the obtaining a uniformity of the airflow into the rectangular ducts give better efficiency and lower pressure drop.

This paper presents results of experimental and numerical research of hydraulic characteristic at rectangular radius elbow without and with splitter radial vanes at different relative position in the domain of elbow. The results are presented through the loss coefficient of elbows which is function of the elbow radius, duct dimensions, angle of turn and Reynolds number. The numerical results of fluid flow domain are comparatively used for presenting the influence of splitter vane on uniformity of discharge distribution in the space of the elbow and on uniformity of fluid flow velocity profile.

The results show that the splitter vanes are proven very valuable for reducing pressure losses and increasing system efficiencies. Designers should add or remove turning

[1] Professor Dr. Valentino Stojkovski, Faculty of Mechanical Engineering, Skopje, North Macedonia, valentino.stojkovski@mf.edu.mk
[2] Assistant Marija Lazarevikj, PhD, Faculty of Mechanical Engineering, Skopje, North Macedonia, marija.lazarevikj@mf.edu.mk
[3] Professor Dr. Viktor Iliev, Faculty of Mechanical Engineering, Skopje, North Macedonia, viktor.iliev@mf.edu.mk

vanes from the design with aim to specify fittings with the highest possible efficiency and to increase system efficiency at every available opportunity.

Key words: rectangular radius elbow, splitter vane, loss coefficient, CFD calculation

1 INTRODUCTION

Ducts are mostly used in air distribution systems to supply or return air. Their shape can be round, square, rectangular or oval. Even though round ducts are most efficient, square/rectangular ducts fit better to building construction – above ceilings and into walls. Moreover, they are much easier to install between joists and studs. The system resistance in ductwork has three components: friction, dynamic and equipment pressure losses. Friction losses depend on air velocity, duct length and diameter (size), and material roughness, whereas dynamic losses are caused by change in air direction from elbows, restrictions or obstructions in the air stream stream such as dampers, filters and coils [1,2,3].

Duct losses occur across fittings and transitions and in order to mitigate them, radius elbows are desirable over square ones if the space allows. When a full radius elbow cannot fit, a part-radius elbow or square elbow with one or more splitters is recommended. A splitter vane is a curved fin placed in an air ductwork at a point of duct direction change. It is used to obtain more uniform flow and to reduce pressure drop [4,5]. Recommendation is to use them in low velocity systems.

In a duct without splitter vanes, the duct walls must absorb the sudden impact of air flow in order to reorient it to the desired direction. Splitter vanes assist in making a smoother and more gradual change in direction resulting in less force transferred. The splitter vanes presence add a small amount of friction, but losses originating from it are negligible compared to the energy lost due to abrupt or significant change in direction [6].

Some research show higher efficiency of square elbow when splitter vanes are added, i.e. more gradual decrement airflow direction change is achieved which causes pressure drop decrease and consequently the required fan power to supply the desired air flow rate is smaller [7].

In this paper, experimental and numerical investigation of the hydraulic characteristic of radius elbow in a rectangular duct with and without splitter vanes is performed. Three cases are compared: empty elbow, elbow with one vane and elbow with two vanes. In addition, the position of the vane in the elbow is changed to gain knowledge of its influence in the flow domain.

2 EXPERIMENTAL SETUP

2.1 Experimental installation

For conducting the experimental research, a physical model of a horizontal closed rectangular duct with radius elbows is manufactured. The measurements are performed in the Laboratory for Fluid Mechanics and Hydraulic Machines at the Faculty of Mechanical Engineering – Skopje. The experimental installation consists of centrifugal fan; reducer and two rectangular ducts connected by an elbow. The reducer is 1m long and decreases the channel height from 400mm to 270mm. The two rectangular conduits have a square cross-section with dimensions 270X270mm and a length of 1m each. The elbow is defined by internal radius (R1) of 150mm and external radius (R2) of 420mm; it changes the air direction from one to other rectangular duct.

The air flow is provided by a centrifugal fan. The experimental setup is shown in Figure 1.

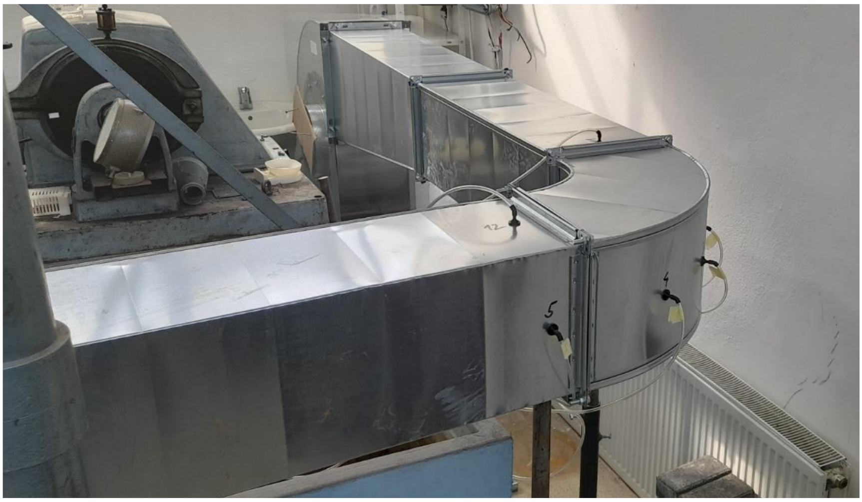


Figure 1. *Experimental setup: fan, reducer, duct and elbow*

2.2 Measuring equipment and procedure

Pressure drop in the elbow and air flow rate in the duct are determined based on pressure and velocity measurement by using adequate measuring equipment and data acquisition system (Figure 2).

Figure 2. *Measuring equipment and data acquisition system*

The pressure is measured in 12 measuring points along the internal and external curved side of the elbow (Figure 3 left) by using a set of 10 digital sensors with with a range of ± 1000 Pa and with U-tubes with manometric liquid – water. For each given measuring point, the corresponding digital sensor and U-tube are connected in parallel. The digital sensors are connected to a pressure acquisition system with the ability to change the sampling time, monitor the pressure values at the measuring points in real time, and archive the data obtained from all sensors simultaneously in a tabular overview.

Two different modes of airflow through the duct are achieved by dimming the suction side of the fan. Velocity is measured in 9 points on the inlet cross-section (Figure 3 right) by the application of anemometer. The methodology of determining volume flow rate of air flowing in the duct is based on measured velocity and therefore computing the flow rate by velocity integration.

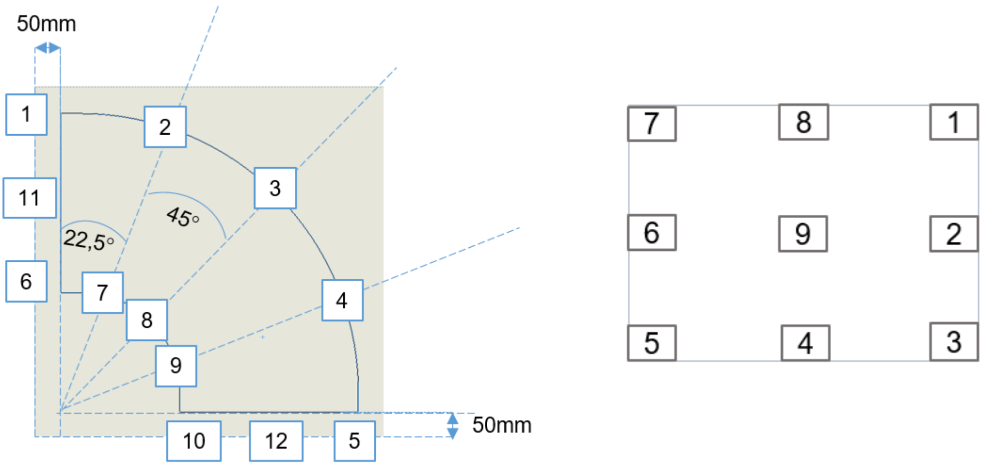


Figure 3. *Location of measuring points in elbow (left) for pressure measurements and in the inlet section (right) for velocity measurements*

Three different elbow constructions are used, i.e. empty elbow – without splitter vanes, elbow with one vane and elbow with two vanes (Figure 4).

Figure 4. *Elbow with one splitter vane (left) and two vanes (right)*

3 NUMERICAL SETUP

3.1 Numerical model and boundary conditions

Steady state flow of air through the rectangular ducts with elbow is modeled and simulated. Air is taken as a compressible fluid with density varying according to the law of ideal gas state, while its other thermophysical properties are constant throughout the domain. The turbulent flow of air is described by the k-ε turbulence model. One flow domain consisting of reducer, two ducts and elbow is present. Mass flow of air at inlet and atmospheric pressure at outlet are applied as boundary conditions in the model (Figure 4).

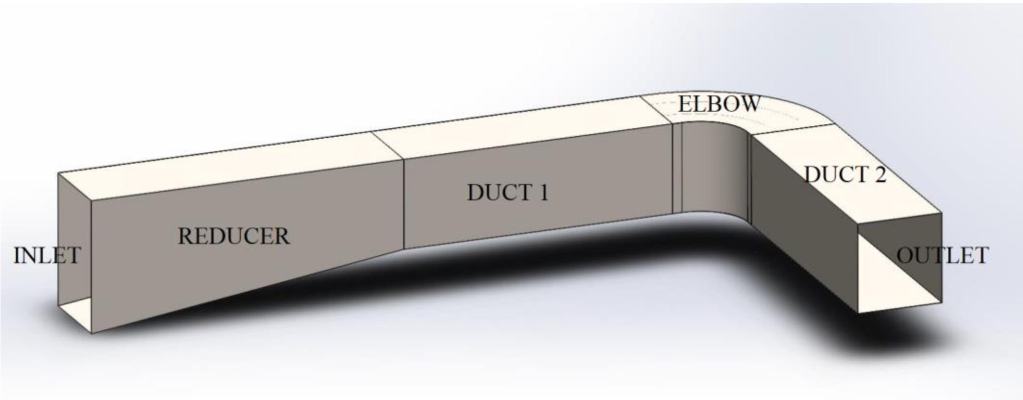
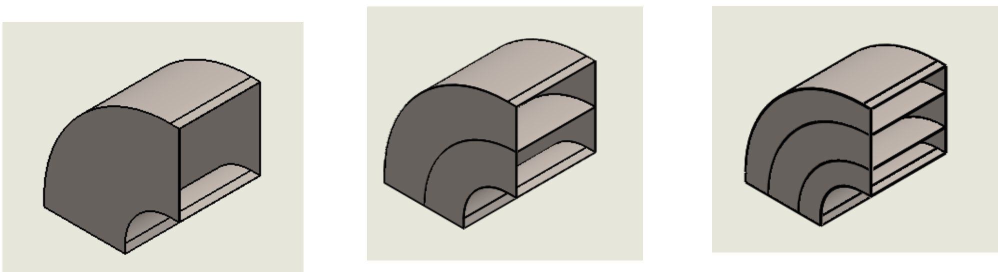


Figure 4. *Numerical model with boundary conditions*

Three geometrical models with different elbow configurations are used, i.e. without splitter vanes (Figure 5a), with one vane (Figure 5b) and with two vanes (Figure 5c). Four flow regimes (air mass flow of 0,3kg/s, 0,6kg/s, 0,9kg/s and 1,2kg/s) are simulated for each configuration.

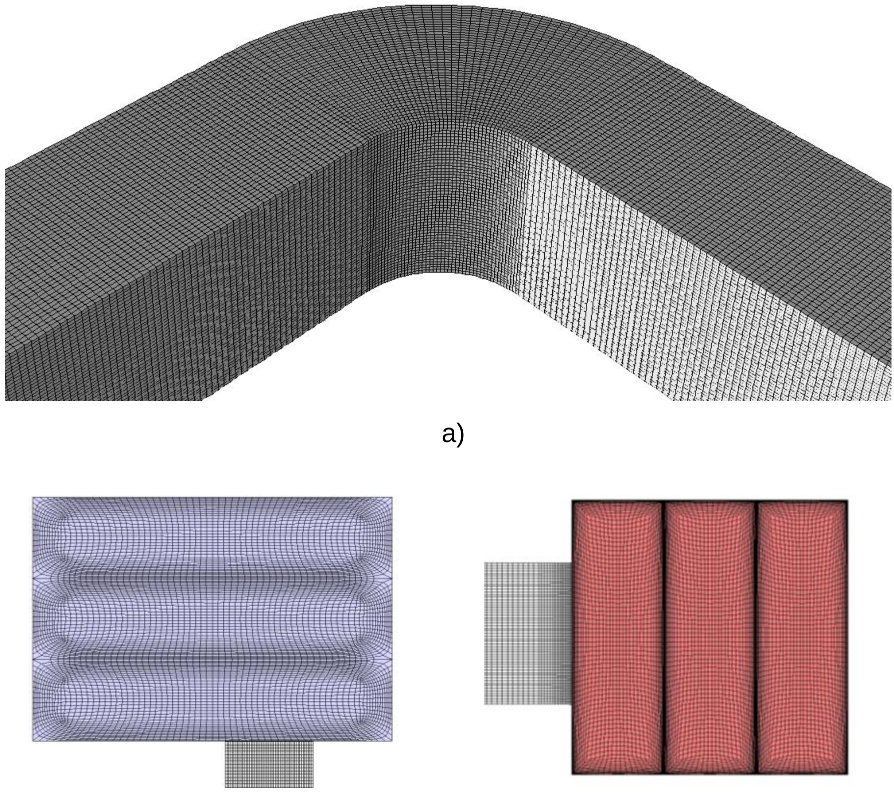


a) b) c)

Figure 5. *Different elbow configurations: a) no vanes, b) one vane, c) two vanes*

3.2 Numerical mesh

The geometrical model is based on the elbow with two vanes. For the configuration with two vanes, the vanes are taken as walls, while for the empty elbow, the vanes are assigned to interiors. This is in order to have the same numerical mesh in each case so that the comparison is made on equal basis. The numerical grid consists of above 2 million cells. The mesh is structural with hexagonal elements and a boundary layer is placed around walls. The numerical mesh at the elbow and ducts is shown in Figure 6a, while the mesh at the inlet and outlet is given in Figure 6b and 6c, respectively.



a)

b) c)

Figure 6. *Numerical grid: a) elbow, b) inlet and c) outlet*

4 RESULTS AND DISCUSSION

4.1 Experimental and numerical results comparison

Experimental measurements are performed using the laboratory installation with elbow without vanes (model 2-0), model with one vane centrally positioned (model 1-0) and model with two vanes (model 2-2).

The experimental values of pressure (p-st) measured in points at the internal and external side of the elbow which position is defined by the angle (0°-inlet and 90°-outlet) for the three geometrical models in similar operating mode (flow velocity from 7,6-7,7 m/s) are given in Figure 7.

Vacuum pressure is obtained on the internal wall (R1) and gauge pressure on the external wall (R2) in all three configurations. Highest underpressure and highest overpressure are obtained at angle of 45°.

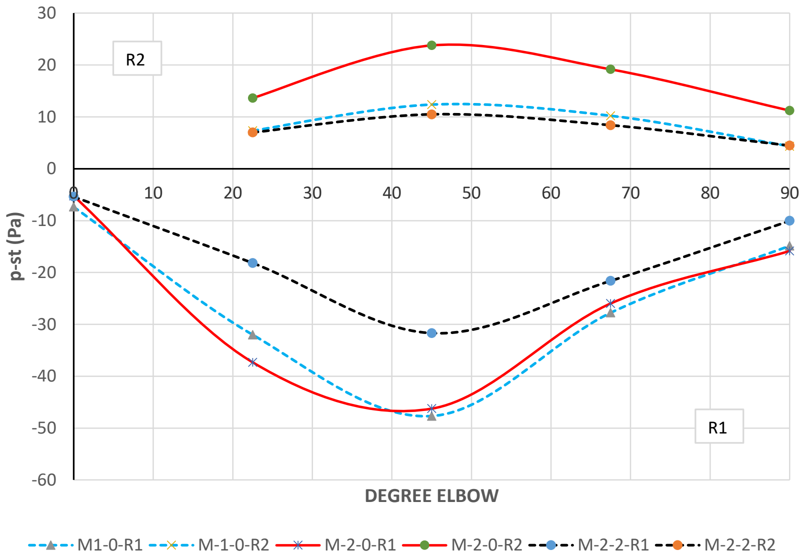
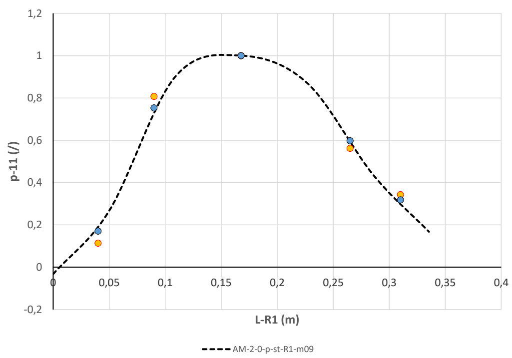
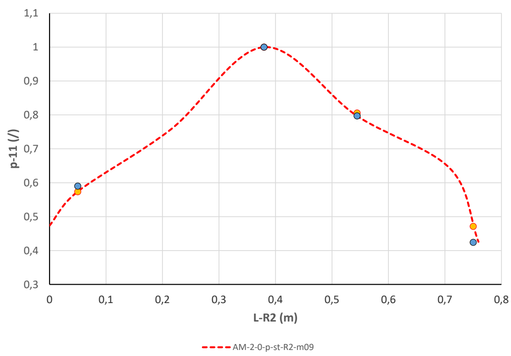


Figure 7. *Experimental results of pressure in measuring points positioned on the internal (R1) and external (R2) wall of the elbow*

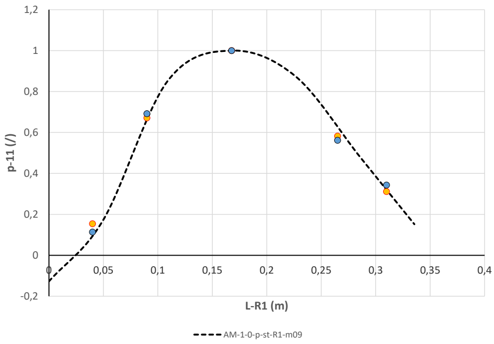
The comparison between experimental and numerical results for pressure distribution on external and internal wall are given as relative values (p-11) to the pressure measured with the probe at angle of 45° (Figure 8). The length of external/internal wall of the elbow in direction from the first to the last measuring point is given on x-axis. Numerical results are given with dashed line, while symbols are used for relative values of measured pressure.

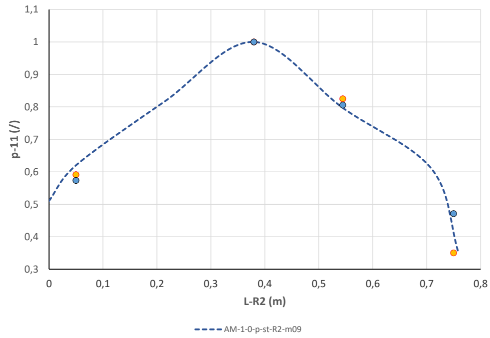


model 2-0: no vanes-на R1



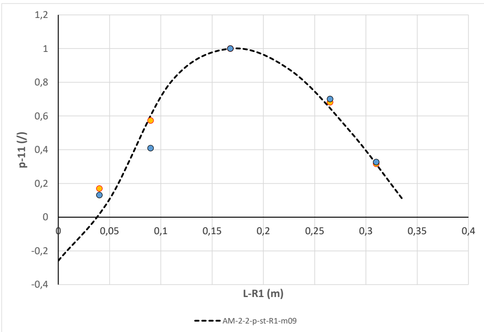
model 2-0: no vanes- R2

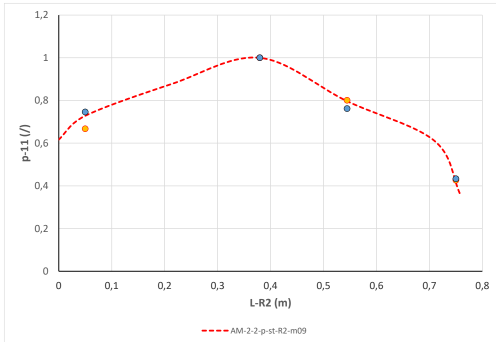




model 1-0: one central vane- R1

model 1-0: one central vane - R2





model 2-2: two vanes- R1

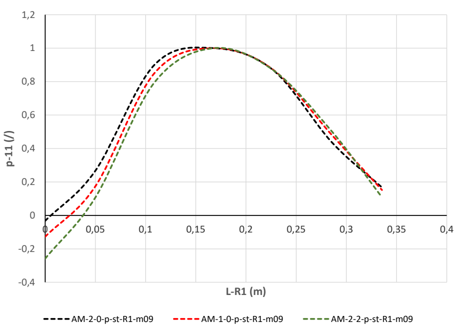
model 2-2: two vanes- R2

Figure 8. *Numerical and experimental results comparison*

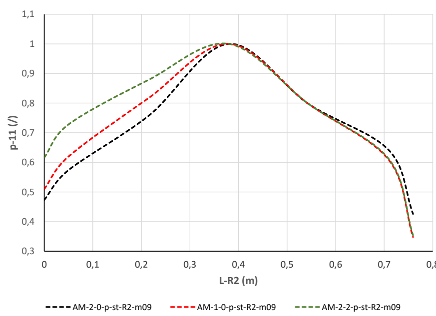
The graphs show alignment of experimental and numerical results for pressure distribution along the external and internal side of the elbow. Thus, the numerical model is validated.

4.2 Influence of splitter vanes

Numerical resuls are used to compare the influence of the splitter vanes position as shown in Figure 9.



a) Pressure distribution along R1

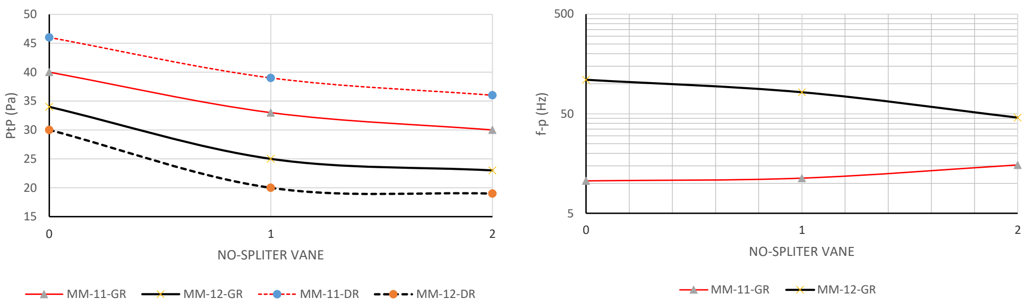


b) Pressure distribution along R2

Figure 9. *Influence of the splitter vanes position in the elbow pressure distribution*

Numerical resuls are used to compare the influence of the splitter vanes position on the elbow pressure distribution as shown in Figure 9. The influence is dominant at the elbow inlet until angle of 45°. The presence of vanes negatively affects the pressure distribution on the internal side, while it contributes to more uniform distribution on the external side of the elbow.

Measured values of pressure in probe no.11 (denoted as MM-11) at the elbow inlet and probe no.12 (denoted as MM-12) at the elbow outlet give the influence of splitter vanes addition on the pressure frequency (determined by FFT analysis) and pulsations intensity (given by the PtP values). The x-axis gives the number of vanes.



a) PtP values of pressure – pressure pulsations intensity

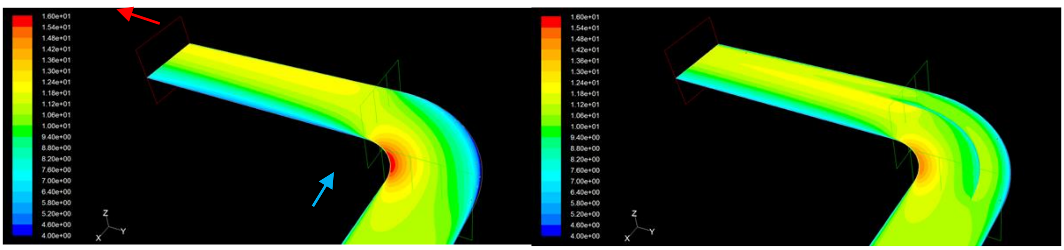
b) Pressure pulsations frequency

Figure 10. *Pressure pulsations intensity and frequency in probes 11 and 12*

The addition of splitter vanes reduces the pressure pulsations intensity both at elbow inlet and outlet. The pressure pulsations frequency is increasing at inlet by adding splitter vanes, but more significant influence of the added splitter vanes is noticed at the outlet where the pulsations frequency is quite decreased.

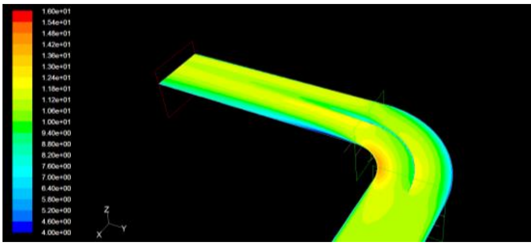
Two additional numerical models are developed to investigate the influence of vanes position in the elbow, i.e. model 2-1 with one vane closer to the external wall and model 2-3 with one vane closer to the internal wall.

The velocity field in the central plane covering the domain from the elbow inlet to the duct outlet obtained for the different numerical models is given in Figure 11.

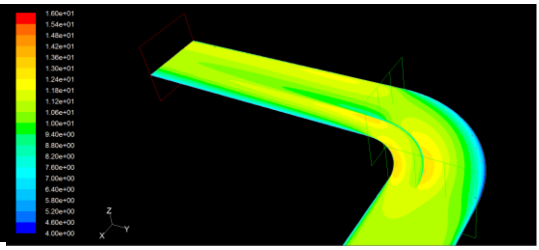


a) model 2-0: no vanes

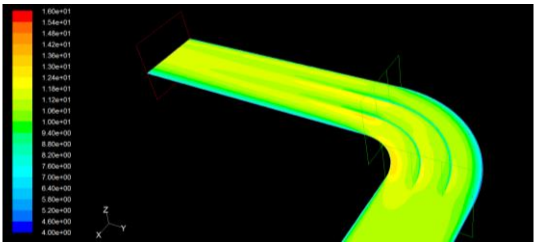
b) model 2-1: one vane closer to external wall



c) model 1-0: one central vane



d) model 2-3: one vane closer to internal wall

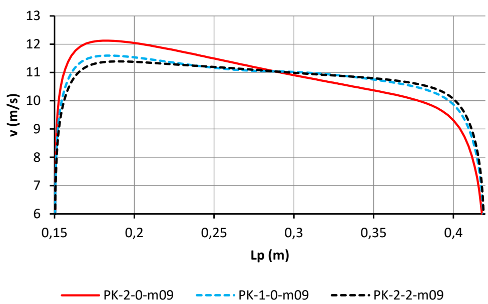


e) model 2-2: two vanes

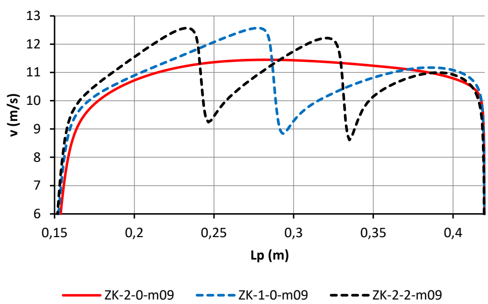
Figure 11. *Flow field (vectors of velocity) of numerically investigated models of elbow*

It can be seen that when there is no vane, the flow is sticking to the external wall of the elbow, with maximal local velocity magnitudes on the internal side. By adding two vanes, there is no flow sticking to the external wall so the flow field is more uniform.

The influence of the splitter vane on the velocity profile uniformity at elbow inlet and outlet (50mm before inlet section and 50mm behind outlet section)-central horizontal section is given in Figure 12.



a) 50 mm before elbow inlet



b) 50 mm behind elbow inlet

Figure 12. *Velocity profile at elbow inlet and outlet*

The addition of splitter vanes gives more uniform velocity profile at elbow inlet contributing to more favorable flow conditions. Velocity profile at elbow outlet are significantly different for each configuration because of the vane influence on the channel outflow.

4.3 Influence of splitter vane position on pressure distribution and hydraulic characteristic of the elbow

Numerically obtained pressure distribution along the external and internal wall of the elbow with splitter vane in different position at constant mass flow rate is given in Figure 13.

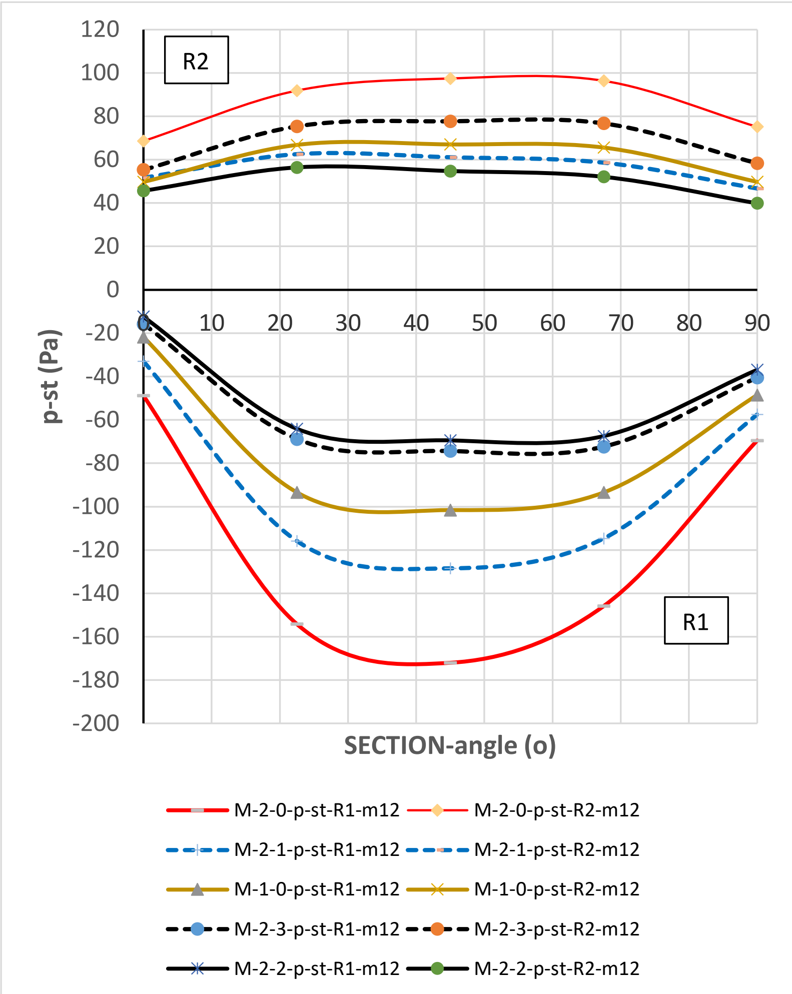


Figure 13. *Pressure distribution along external and internal wall of elbow*

The comparison of different splitter vane positions so as the number of vanes in the elbow emphasizes the changes in pressure intensity.

Smallest difference in pressure between the external and internal wall of the elbow and more uniform pressure distribution is obtained by adding two splitter vanes in the elbow.

Hydraulic losses of elbow are defined as difference between average pressure at 50mm before elbow inlet and average pressure at 50mm behind elbow outlet. The elbow hydraulic losses are calculated at different air mass flow rates (0,3; 0,6; 0,9; 1,2 kg/s) and given in Figure 14.

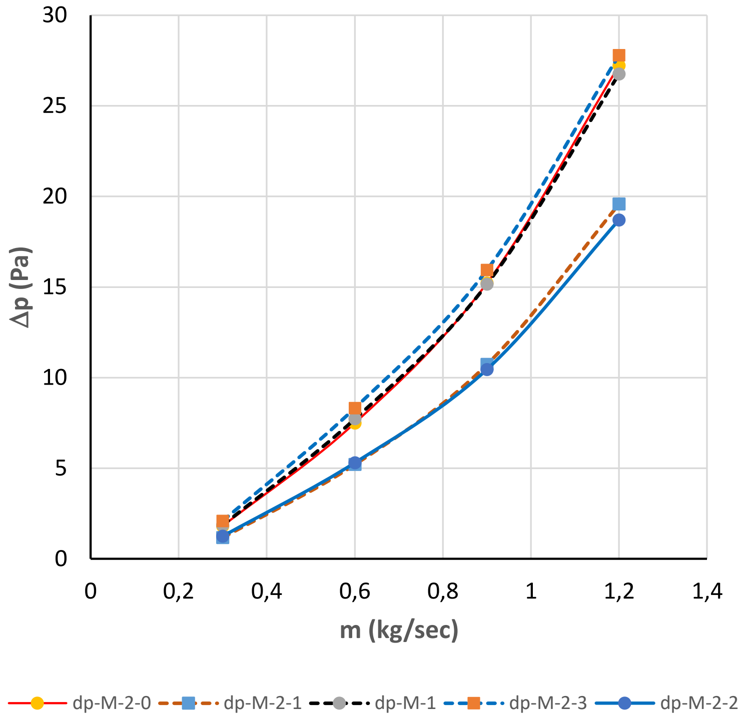


Figure 14. *Elbow hydraulic losses for different elbow configurations*

It can be seen that if one vane is added in the elbow, its position significantly affects the hydraulic characteristic, i.e. hydraulic losses are higher when the vane is closer to the internal wall of the elbow and hydraulic losses are lower when the vane is closer to the external wall. Moreover, if the vane is centrally positioned, there is almost no difference in the hydraulic characteristic compared to the elbow without vanes. The addition of two vanes reduces hydraulic losses in the elbow.

5 CONCLUSIONS

In this paper, exeperimental and numerical analysis of the number of splitter vanes and the vane position in the elbow is performed. The numerical model is validated by verifying the numerical results by comparison with the measurements. It was obtained that the splitter vane position affects the hydraulic characteristic.

The experimental and numerical investigation of the influence of the vane position in the elbow connecting two ducts with square cross-section show that locating a vane close to the external wall contributes to reducing hydraulic losses so as the addition of two vanes symmetrically in relation to the elbow boundary walls.

The experimental and numerical analysis is performed to resolve the dillema about the influence of the splitter vane position in the elbow. Further steps need to be taken in this research to improve the effects of adding the vane.

REFERENCES

[1] http://ibse.hk/MECH3423/MECH3423_1516_07-airside02.pdf
[2] Bhatia, A., HVAC How to size and design ducts, https://www.cedengineering.com/userfiles/HVAC%20-%20How%20to%20Size%20and%20Design%20Ducts%20R1.pdf
[3] https://energy-models.com/ductwork-design-program
[4] https://encyclopedia2.thefreedictionary.com/turning+vane
[5] Rasuo B., Dinulovic M., Trnicic M., Stamenovic M., Milosevic M., Curcic M., (2021). A study of aerodynamic noise in air duct systems with turning vanes, FME Transactions, vol. 49, no. 2, p.p. 308-314
[6] http://www.sheetmetaljournal.com/?p=690
[7] https://buildingengineer.wordpress.com/2009/12/11/turning-vanes-necessary-component-or-efficiency-reduction-device/