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Investigation of Curve Diffuser Performance by Means of Installing Passive Flow Control Device: Woven Wire Mesh Screen

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Abstract: Heating, venting, and air-conditioning which usually called HVAC is a system of several technologies for controlling temperature or purity air in enclosed spaces. The performance of the HVAC system will reduce without the existing of diffuser. Other than that, there are several types of techniques that can be used to control the flow and it include the passive flow control device which most of them can increase the performance of the diffuser. In the present work, the potential of woven wire mesh screen as a passive flow control device to improve the performance of curved diffuser is investigated in this study. This study considers different weave patterns which include of plain weave, twill weave and satin weave. Then, the wires diameter used for all the woven wire mesh screen is 1.2mm with 6mm of pitch and the flow type in this study is assumed as a turbulent flow with considered Reynold number of $Re = 4.527 \times 10^4 \sim 1.783 \times 10^5$. The results show that plain weave is the best mesh pattern to install in a 90 degree curved diffuser to improve the flow uniformity. However, the use of woven wire mesh in the 90 degree curved diffuser will cause the pressure drop due to the presence of the woven wire mesh screen.

Keywords: HVAC, Diffuser, Flow Control Device, Woven Wire Mesh, Ansys.

1. Introduction

Heating, venting, and air-conditioning which usually called HVAC is a system of several technologies for controlling temperature or purity air in enclosed spaces. Most of the HVAC system is acting as an air ducting system or a system that used for warming or cooling a space. In the HVAC system, a diffuser is a common part that able to reduce the energy losses or change the direction of the flow. The performance of the HVAC system will reduce without the existing of diffuser. Therefore, the statement shows the important of diffuser in HVAC system to distribute the flow evenly with desired flow direction. Other than that, a passive flow control device can be use in order to increase the performance of the diffuser. Passive flow control is a method which required no power sources and

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controller. The used of passive flow control device is not only to increase the performance of the diffuser but also decrease back flow drag,

According to Nohseth and Isa (2017), the effect of airfoil aerodynamic on turning diffuser was studied and it stated that it has successfully improved the diffuser performance. Other than that, a study on flow control capability of woven wire mesh screens was conducted by using CFD simulation that stated woven wire mesh screens affect the flow loss coefficients [1]. By collecting the data of previous study and conducting CFD simulation, the woven wire mesh screen is studied in this study.

2. Methods and Parameters

This study is start with data collection and modelling process. These processes can be done at the same time since the modelling and data collection process are not going through the same device. By using Solidwork software, the model is built. Then, the modelling drawing file is import into the software ANYSYS CFD code Fluent and meshing process is done. After that, the parameters of boundary condition and solver setup are key-in correctly and simulation is done until the desired data is obtained. After getting the desired data, comparison and discussion are done based on the data collected from the simulation and the data collection process.

2.1 Modelling

Modelling is the process of building a model. The models need to be built in this study are 90-degree diffuser and woven wire mesh screen. The installation of woven wire mesh screens in this study are located before the inlet of the 90 degree curved diffuser and after the outlet of the 90 degree curved diffuser.

2.1.1 Validation & Verification

Validation and verification are step which assist in determine the suitable setting for intensive simulation. It is done by running simulations using the input parameters of selected experimental study but some different parameters in the settings are necessary. It including the model type and the mesh setting which affect the number of nodes and cells of the model. For this study, the validation and verification are done by referring the previous study done by Chong et al (2008) on a parametric study of passive flow control for a 90 degree curved diffuser.

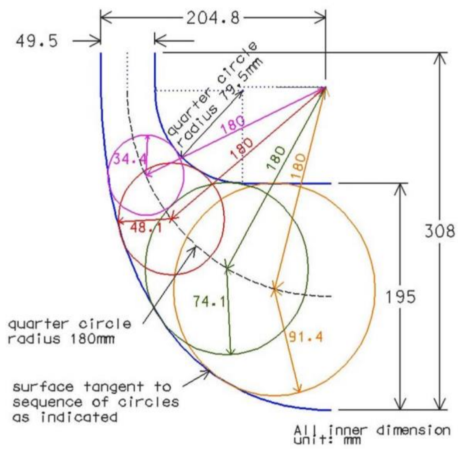


Figure 1: Construction Line of Curved Diffuser [10]

The model for validation and verification is built according to the parameter of model in the study of Chong et al (2008). The model start with a centrifugal fan connected with a 49.5mm diameter transition pipe. Then, it continuous with a 2D diffuser and settling chamber with a divergence angle of

4.5 degree and cross-sectional area of 195×49.5 〖mm〗^2. After that, the 400mm long settling chamber is connected to the 90 degree curved diffuser. The construction line of the curved diffuser is shown in Figure 3.2 and then its parameters are listed down at Table 3.1. Moreover, the completed models for validation and verification are shown in Figure 3.3.

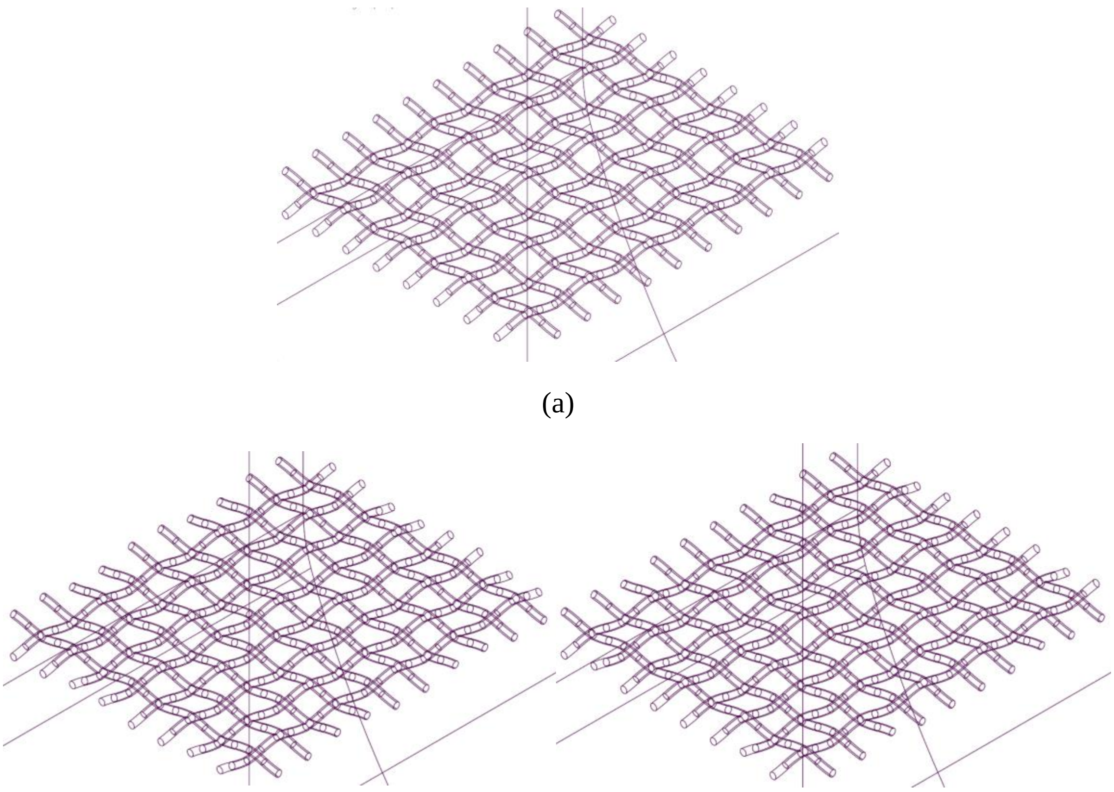
2.1.2 Intensive Simulation

The model for intensive simulation only consider the part of 90 degree curved diffuser without the connection of the other section or pipe. The parameters of the intensive simulation for the curved diffuser are recorded in Table 3.2. The outlet of this model is extended too in order to remedy the flow for results with more accuracy.

Table 1: Parameters of Curved Diffuser for Intensive Simulation

W_1 (mm)	X_1 (mm)	W_2 (mm)	X_2 (mm)	r_{in} (mm)	L_{in} (mm)	r_m (mm)	L_m (mm)
50	130	108	130	139.1	218.5	196.74	309.03

First thing that need to be consider in constructing a model for woven wire mesh screen is the structure of the screen and the weave pattern. The weave pattern considered is plain, twill and satin pattern. Then, the structure of the wire mesh which include mesh opening and pitch. After some researches on several previous study related to wire mesh, the parameters of woven wire mesh screen used in this study is decided to have a wires diameter of 1.2mm and 6mm of pitch.



(a)

(b) (c)

Figure 2: Model for Woven Wire Mesh Screen (a) Plain Weave (b) Twill Weave (c) Satin Weave

Figure 2 shows the Models for woven wire mesh screens which are built according to Figure 2.6. The difference of the woven wire mesh screens is based on its weave pattern. Plain weave is the most basic weave pattern with each warp wire passing over each other simply. Then, twill weave above used a designated of 2/2 and satin weave used a designated of 4/1 as the number or times of weft wires and warp wires go over and under. Thus, it can be observe that the wires in a twill weave are upside-down for every two wires while satin weave will have the wires pattern upside-down for every four wires following by one wire repeatedly which represent to the number of 2/2 and 4/1 as the number of weft wires and warp wires go over and under.

After the 3D model is built by extruding the base object, the model is imported from SolidWorks to ANSYS Fluent Workbench. Then, the actual outlet was extended to remedy the flow with a length which equal to the center curve length of the 90 degree curved diffuser L_m [13].

2.2 Meshing

After the modelling process, meshing process is required before the solver setup. Meshing is the step where to generate numerical grid from the model into nodes and cells.

It is very important to refine the grid along the inner and outer wall since these are the regions of 90 degree curved diffuser that involve changes of variable. Near wall treatment is done in order to refine the grid. Different of wall treatment will have different range for the size of wall-adjacent cell, y^+. Standard and non-equilibrium wall treatment will have a range of $30 < y^+ < 60$, while enchanted wall treatment will have a range of $0.5 < y^+ < 1.8$ [13].

After define the near wall treatment, the normal distance from the wall or called a first layer thickness is calculated to refine the selected region in ANSYS meshing process. The first layer thickness can be determined through the formula below:

$$y^+ = \frac{y u_\tau}{v} \quad (1)$$

Where,

$y =$ normal distance from the wall (m)

$u_\tau =$ friction velocity (m/s)

$v =$ kinematic viscosity (m/s)

$$u_\tau = V\sqrt{\frac{C_f}{2}} \quad (2)$$

Where,

$V = flow\ velocity\ (m/s)$

$$\frac{C_f}{2} \approx 0.039 Re^{-1/4} \quad (3)$$

2.3 Boundary Conditions

The boundary condition with the fluid properties used in both validation & verification and intensive simulation process are discussed. The fluid types in this study is assumed as air with $1.225 kg/m^3$ density and 1.789×10^{-5} of viscosity. Other than that, the value of inlet velocities are calculated based on the Reynold number selected. Therefore, the inlet velocity used in validation & verification is 10.649 m/s with Re=52640 while the range of inlet velocity and Reynold number used in the intensive simulation is 9.159 m/s to 25.553 m/s and 45270 to 126300 respectively.

2.4 Measurement and Condition Setup

Verification or a Grid Independence Test (GIT) have a different mesh nodes or called mesh cells as the condition setup. There is five set of numbers for the mesh nodes used in the Grid Independence Test. Then, there is three turbulence model used for the validation condition which is k-epsilon Realizable, k-omega SST and k-epsilon RNG where the results of these model will be compared to the experimental result done by Chong et al (2008).

Moreover, the intensive simulation for this study will also have its own condition setup where the Reynold number used and the mesh pattern of the woven wire mesh screens are consider. The mesh patterns of the woven wire mesh are plain weave, twill weave and satin weave whereby the results of the diffuser with the mesh pattern setup will be compared with an empty curved diffuser. Then, the best pattern is selected and different Reynold number is set as the condition to determine the effect of Reynold number on the performance of woven wire mesh.

3. Results and Discussion

3.1 Validation & Verification

This study start with the validation and verification with the numerical simulation based on the study of Chong et al (2008). As mentioned in this study, the validation is done with the different model of Realizable, SST and RNG. Then, the results are analyzed and compared to the experiment model.

Table 2: Pressure Coefficient for Curved Diffuser with Different Model

Turbulence Model	Pressure Coefficient, C_p	% Deviation
Experiment	-0.81	-
Realizable	-0.92	13.6
SST	-0.16	99.3
RNG	-0.423	422

In most cases, a 5% of deviation is acceptable for a CFD calculation. However, the available deviation percent for each study may different according to the application, mesh generation, etc. For this study, a 15% of deviation is used for the validation considering the cases and meshing done.

In Table 2, only the result of realizable model is within the range of the allowed deviation percentage. Therefore, it is assumed that the suitable model use for this study is a realizable model.

Grid independence test is done as the verification after the turbulence model is defined. It is completed by having several different mesh nodes through the setting in the meshing process. Five set of mesh nodes is used with the number of mesh nodes increasing according from set 1 to set 5 and set 1 is having the least mesh nodes value while set 5 is having the most mesh nodes value.

Table 3: Grid Independence Test (GIT) for Realizable Model

Mesh Nodes	Pressure Coefficient, C_p	% Deviation
Set 1	-0.917	27.01
Set 2	-1.291	78.81
Set 3	-0.740	2.49
Set 4	-0.758	4.99
Set 5	-0.722	-

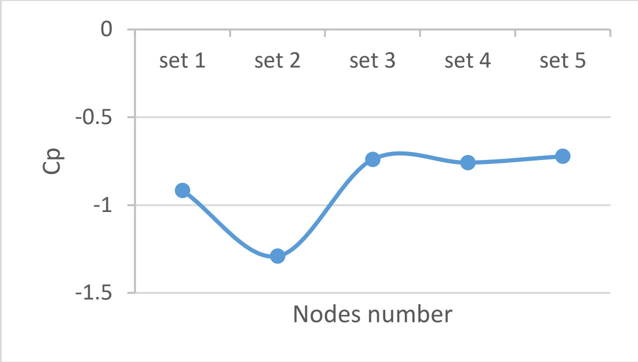


Figure 3: Grid Independence Test (GIT) for Realizable Model

Based on the table and figure for grid independence test, set 5 is used to compared by the other set since set 5 is having the finest mesh setting. There allowable deviation percentage for a grid independence test is only 5% since it only consider about the meshing setup. Set 1 and set 2 are having a deviation percentage above 5% which is 27.01% and 78.81 respectively. It means that the mesh nodes setting for set 1 and set 2 is not suitable to use on the intensive simulation since there is still a huge effect for the mesh nodes on the simulation results. On the other hand, set 3 and set 4 is having a deviation percentage below 5% which is in the allowable range which is 2.49% and 4.99% respectively. Since set 3 is having the lowest percentage of deviation, its meshing setup is selected and used for the intensive simulation.

3.2 Intensive Simulation

After the validation and verification process, the conditions setup for the intensive simulation that depend to it are the turbulence model and the meshing setup. The selected turbulence model is realizable model while having an element size of 0.0075mm for meshing setup.

Table 4: Summary Result for Intensive Simulation

Mesh Pattern	Reynold Number	Pressure Coefficient, C_p	Flow Uniformity
Empty	45270	1.21	2.755
	52640	1.22	2.293
	75800	1.22	4.050
	99500	1.23	4.935
	126300	1.24	6.704
Plain	45270	0.64	0.462
	52640	0.69	0.448
	75800	0.73	1.975
	99500	0.73	1.986
	126300	0.80	2.159
Twill	45270	0.66	0.478
	52640	−1.38	4.235
	75800	−2.65	10.197

	99500	−0.23	15.432
	126300	0.78	2.104
Satin	45270	0.14	7.118
	52640	0.16	25.802
	75800	0.62	0.805
	99500	1.1	31.787
	126300	−6.51	18.989

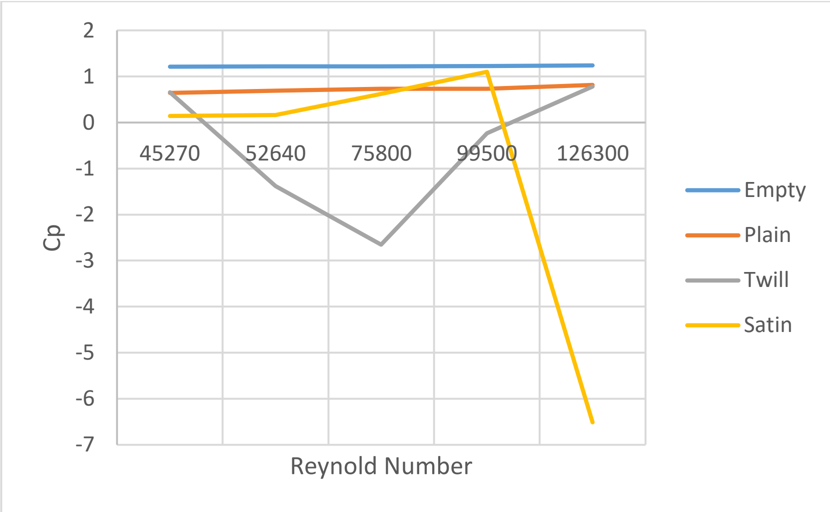


Figure 4: Summary Graph for Pressure Coefficient, C_p

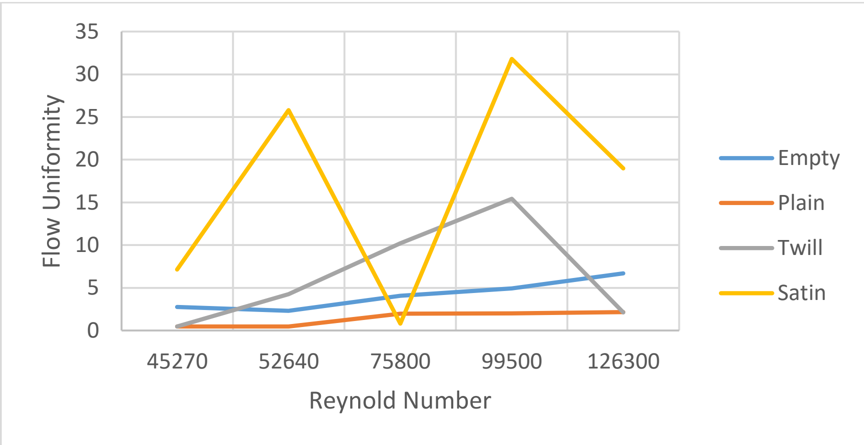


Figure 5: Summary Graph for Flow Uniformity

Based on Figure 4, plain weave wire mesh is having the most similar graph pattern with the bare diffuser (Empty case) and it is having the most similar value of pressure coefficient at 0.73 with the Reynold number of 99500. It is observed that all the wire mesh is having a lower value of pressure coefficient compare to the bare diffuser (Empty case). Thus, it can be said that the woven wire mesh has no effect in improving the pressure coefficient. Other than that, Figure 5 tells that the plain weave wire mesh is having the most similar graph pattern with the bare diffuser (Empty case). Satin weave wire mesh and Twill weave wire mesh are having a worse flow since they have a high value of flow uniformity. Thus, the plain weave wire mesh is the most effective in improving the flow uniformity among plain, twill and satin weave wire mesh. Therefore, it can be said that a plain weave woven wire mesh is able to improve the flow uniformity of a 90 degree curved diffuser by having some pressure drop within it.

4. Conclusion

As a conclusion, this study was carried out successfully to conduct numerical simulation for determine the best mesh pattern among the woven wire mesh in improving the performance of a 90 degree curved diffuser. The mesh pattern used to carry out the study are plain weave, twill weave and satin weave. The parameters of intensive simulation were validated. The best turbulence model for this study is a realizable k-epsilon turbulence model which product the least deviation of 13.6% as a complicated cases. The results show that plain weave is the best mesh pattern to install in a 90 degree curved diffuser to improve the flow uniformity. However, the use of woven wire mesh in the 90 degree curved diffuser will cause the pressure drop due to the presence of the woven wire mesh screen.

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References

[1] Okolo, P & Zhao, K & Kennedy, J & Bennett, G. (2019). Numerical assessment of flow control capabilities of three dimensional woven wire mesh screens. European Journal of Mechanics - B/Fluids. 76. 10.1016/j.euromechflu.2019.03.001.

[2] Yong, H & Nordin, N & Rasidi, S & Yong, T & Anuar, M. (2022). Effect of Angle of Turn on Loss Characteristics and Flow Rectification of Curve Diffuser. CFD Letters. 14. 38-51. 10.37934/cfdl.14.1.3851.

[3] Ali, Hasan & Fales, Roger. (2021). A review of flow control methods. International Journal of Dynamics and Control. 9. 10.1007/s40435-020-00730-y.

[4] Seyam, Shaimaa. (2018). Types of HVAC Systems. 10.5772/intechopen.78942.

[5] Nordin, Normayati & Abdul Karim, Zainal Ambri & Safiah, Othman & Raghavan, Vijay & Md Seri, Suzairin & Adzila, Sharifah & Taib, Ishkrizat & Ramli, Yahaya. (2017). Assessment of Turbulence Model Performance Adopted Near Wall Treatment for a Sharp 90° 3-D Turning Diffuser. Communications in Computer and Information Science. 751. 259-273. 10.1007/978-981-10-6463-0_23.

[6] Fernandez-Gamiz, U., Z, E., Boyano, A., A, I., & Uriarte, I. (2017). Five Megawatt Wind Turbine Power Output Improvements by Passive Flow Control Devices. Energies, 10(6), 742. From, https://doi.org/10.3390/en10060742

[7] Haneen, S & Roslan, E & Akhiar, A & Ahmad Z, M. F. M. & Salleh, F & Isa, R & Shamsuddin, A. H. (2020). Study on benefit of guide vane for vertical axis wind. IOP Conference Series: Earth and Environmental Science. 476. 012081. 10.1088/1755-1315/476/1/012081.

[8] Kee Chien Ting. (2005). Three Dimensional Finite Element Modelling of Non-Newtonian Fluid Flow Through a Wire Mesh. 2.1 Weave Patterns of Wire Meshes.

[9] Peng, Y & Xu, G & Luo, Xiang & Li, H & Liu, Y. (2017). Experimental study on the influence of wire diameter on the internal flow behaviour of woven metal screens. IOP

Conference Series: Materials Science and Engineering. 164. 012003. 10.1088/1757-899X/164/1/012003.

[10] T. P. Chong, P. F. Joseph, and P. O. A. L. Davies, (2008). A Parametric Study of Passive Flow Control for a Short, High Area Ratio 90 deg Curved Diffuser. 111104-12 / Vol. 130.

[11] Nohseth, N. & Mat I, N. (2017). Effects of changing airfoil aerodynamic characteristics on turning diffuser performances. AIP Conference Proceedings. 1831. 020019. 10.1063/1.4981160.

[12] Yong, Teo & Nordin, Normayati & Manshoor, Bukhari & Karim, Zainal & Rasidi, Shamsuri & Yong, Hau & Shariff, Muhammad & Anuar, Muhammad. (2021). Effect of Expansion Direction/Area Ratio on Loss Characteristics and Flow Rectification of Curve Diffuser. CFD Letters. 13. 52-68. 10.37934/cfdl.13.10.5268.

[13] Normayati Nordin & Safiah Othman & Zainal Ambri Abdul Karim & Vijay R. Raghavan, (2014). Numerical Investigation of Turning Diffuser Performance: Validation and Verification.

[14] Genç, M. S. , Koca, K., Demir, H., & Açıkel, H. H. (2020). Traditional and New Types of Passive Flow Control Techniques to Pave the Way for High Maneuverability and Low Structural Weight for UAVs and MAVs. In (Ed.), Autonomous Vehicles. IntechOpen. From, https://doi.org/10.5772/intechopen.90552

[15] Saran, S., Gurjar, M., Baronia, A. et al. Heating, ventilation and air conditioning (HVAC) in intensive care unit. Crit Care 24, 194 (2020). From, https://doi.org/10.1186/s13054-020-02907-5

[16] Dorri, Altin & Alcani, Majlinda & Maraj, Altin. (2015). BEHAVIOR OF A HVAC AIR DIFFUSER IN DIFFERENT CONDITION.

[17] Moghaddam, T. & Banazadeh, N. (2017). On the Active and Passive Flow Separation Control Techniques over Airfoils. IOP Conference Series: Materials Science and Engineering. 248. 012009. 10.1088/1757-899X/248/1/012009.

[18] Oktay, T. & Kanat, Ö. (2017). A Review of Aerodynamic Active Flow Control.

[19] Harris, E & Shoji, T & Bernard, A & Schein, S & M'Closkey, R & Cortelezzi , L & Karagozian, A & Benetti, m. (2022). Effects of Controlled Vortex Generation and Interactions in Transverse Jets. Physical Review Fluids. 7. 013902. 10.1103/PhysRevFluids.7.013902.

[20] Jessam, Raed & Al-Kayiem, Hussain & Nasif, Mohammad & Jaddoa, Ameer. (2020). Experimental and Numerical Assessment on S-shaped Diffuser performance with different Turbulence Intensity.

[21] Nie, L & Yin, Y & Yan, L & Zhou, S. (2021). Pressure Drop Measurements and Simulations for the Protective Mesh Screen Before the Gas Turbine Compressor. 10.3233/ATDE210277.

[22] Yong, T & Nordin, N& Manshoor, B & Karim, Z & Rasidi, S & Yong, H & Anuar, M. (2021). Effect of Expansion Direction/Area Ratio on Loss Characteristics and Flow Rectification of Curve Diffuser. CFD Letters. 13. 52-68. 10.37934/cfdl.13.10.5268.

[23] Marouf, A. & Truong, H. & Hoarau, Y. & Gehri, A. & Charbonnier, D. & Vos, J. & Braza, M. (2022). CFD simulations of active flow control devices applied on a cambered flap. 10.2514/6.2022-1545.

[24] Knefel, Markus. (2015). WOVEN WIRE MESHES - THEIR CHARACTERISTICS AND SELECTION CRITERIA.

[25] Coșoiu, Costin & Georgescu, Andrei-Mugur & Degeratu, Mircea & Vladuţ, Alexandru Cezar & Chiulan, Elena-Alexandra. (2020). NUMERICAL PREDICTIONS OF THE FLOW AROUND A SMALL DUCTED WIND TURBINE EQUIPPED WITH PASSIVE FLOW CONTROL DEVICES. Proceedings of the Romanian Academy - Series A: Mathematics, Physics, Technical Sciences, Information Science. 21. 155-162.

[26] Nasir, Muhammad & Bayu Dwianditya, Ignasius & Suryopratomo, Kutut & Sihana, Sihana. (2018). The effect of inlet curvature and flange on wind turbine diffuser performance. E3S Web of Conferences. 43. 01025. 10.1051/e3sconf/20184301025.