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Aerodynamic Forces Numerical Estimation for Cross Flow Over Three Circular Cylinder Inline Arrangement

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A B S T R A C T

A two-dimensional numerical simulation was performed using the program (Ansys-Fluent 22.1), for air flow around three circular cylinders to get the knowledge of the characteristics of aerodynamic forces (drag & lift) where they are arranged in tandem at various ratios of spacing (L/D =1, 1.2, 1.5, 2, 3, 45) for constant Reynolds number (Re =1171). This study was done using the turbulence model (k-ω SST). The findings demonstrated that there is vortex simple shedding when spacing ratios where (L/D=1, 1.2, 1.5), vortex shedding begins when spacing ratios (L/D=2, 3), while when spacing ratio (L/D=45) the cylinders behave as if they were a single and independent cylinder because of the big distance of the cylinders from each other. Also, the pressure coefficient values for the first cylinder are greater than the pressure coefficient values for the second and third ones, the drag coefficient values for the first cylinder are positive and greater than the drag coefficient values for the second and third cylinders in all the study cases, the pressure fluctuations and the vortex shedding affecting the lift coefficient values so it oscillates between positive and negative and are close to be zero.

1. Introduction

Cylinder has been considered as one of the most broadly used geometric shapes in many engineering fields. They have a look at gliding around a cylinder paves the way to reading extra complicated shapes. There is many engineering software for gliding around a cylinder, marine pipelines, warmth exchangers, and suspension bridges. Research was done in this field [1].

Kartik C.B. et. al [2] finished a realistic and theoretical look at airflow around a round cylinder with unique diameters (7.5 & 10 cm) and unique glide speeds (8.35, 9.27, 10.23 m/s). Researchers used a wind tunnel and program (Ansys-Fluent) of their look at. Hyun A. Son et. al [3] performed a theoretical look at primarily based totally on the finite quantity approach that used a program (Ansys Fluent 19. 2) to estimate the drag pressure of the glide around a three-dimensional round cylinder. The turbulence model (k-ω SST) became extensively utilized of their look at. A numerical simulation of two-dimensional unsteady glide around cylinders organized in tandem inside the unfastened glide area was achieved with the aid of Behzad Ghadiri Dehkordi et. al [4] to look at the traits of laminar and turbulent glide at Reynolds numbers (Re = 1×102, 2×102, 2.2×104). This simulation was based on the finite volume method. H. X. Hu et. al [5], completed a three-dimensional numerical study of the cross flow on tandem two cylinders at spacing ratios (L/D= 1.5, 2.5) and Reynolds numbers (Re = 2.8×105, 7×105), they used the turbulence model (k-ω SST) to obtain the characteristics of flow around the cylinders in this study. Yongtao Wang [6], conducted a numerical study of the flow vortex shedding of two cylinders with unique diameters and arranged in tandem, and they used finite element method to solve Navier-Stock equations, for a Reynolds number (Re = 100). Paula R. T. & Eric Didier [7], conducted a numerical simulation of two cylinders arranged in tandem at Reynolds numbers, the researchers depended on finite element method. They divided the analysis of the result into two parts: when the spacing of ratios (L/D = 1.5, 6.0) and at the Reynolds numbers (Re = 100), and when the distance of ratios (L/D = 5.25) and when the Reynolds numbers range (Re =100-400). P. Sooraj et. al [8], conducted an experimental study of three adjacent circular cylinders with different aspect ratios (1.5 ≤ G/D ≤ 4.0) and low Reynolds number (90 ≤ Re ≤ 560) to analyze the flow domain and obtain the flow structures instantaneous and average with particle image velocity (PIV) technology. D. S. K. Raddy et. al [9] performed a theoretical study of the flow around four cylinders arranged together. The study included the effect of change horizontal distance between cylinders (L/D = 1.5, 2, 2.5, 3) at constant Reynolds lift and drag forces number (Re = 200). The turbulence model (k-ω SST) was also used in this study. Xiaobing Liu et. al [10] conducted an experimental study of three equidistant circular cylinders arranged in spatial ratios (L / D = 1.2 - 4.0) and Reynolds number (Re = 6.4 × 104), as well as the characteristics of the distribution of the fluctuating aerodynamic force and air pressure are studied. The fluctuating aerodynamic characteristics can be divided into three sections, the spatial ratios are small (1.2 ≤ L/D ≤ 2.0), medium (2.0 < L/D < 3.5) and large (3.5 ≤ L/D ≤ 4.0). S. A. Ali [11] conducted an numerical study two dimensional to analyze turbulent airflow in a channel with different sides of the configurations (quarter of acircular, square and triangle) using COMSOL Multiphysics software to improve the process of heat transmission and airflow properties, and used k-ε model and Reynolds number (Re = 9000-18000). S. A. Ali et. al [12] conducted a numerical simulation to check fluid flow properties and the transmission of heat using types of dimples (square, circular and trianglar) and compared them with a three-dimensional empty tube, the condition is steady state and the Reynolds number (Re = 3500-7000), used program (Ansys-Fluent 23.2) and k-ε model. A. MENTEŞE and S. BAYRAKTAR [13] conducted a two-dimensional numerical simulation of the analysis of unsteady flow on cylinders with a cross section, where the effect of the distance between the cylinders was studied on the flow characteristics of two circular cylinders tandem and side-by-side at the Reynolds number (Re = 2×10^4), used Spalart-Allmaras turbulence model.

The aim of study is the effect of the horizontal distance between the three cylinders on the distribution of pressure and the form of flow and the aerodynamic powers (drag and lift) and the distance rates were chosen to compare the results with other studies,this work was distinguished by studying the state of the second cylinder that does not front free flow and there is no waking area behind it.

2. Governing Equations and Numerical Method

Two-dimensional Navier-Stoke equations are solved in the steady state of an incompressible flow, the continuity and momentum equations can be written as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] \qquad (2)$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] \qquad (3)$$

Where equation (1) refers to the continuity equation, equations (2) and (3) refer to the momentum equation for the X and Y directions, respectively.

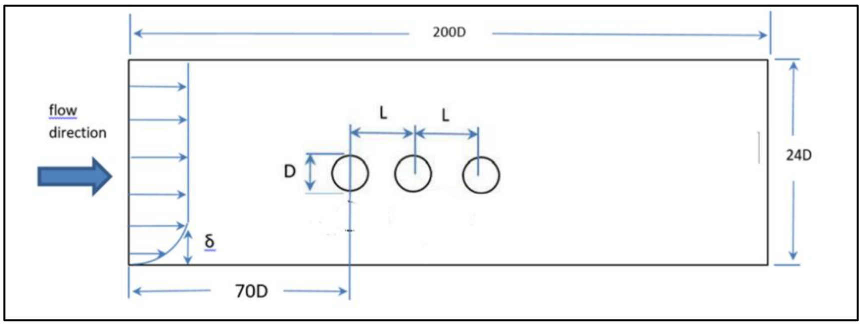

Fig. 1. Calculational range for three cylinders

Figure 1 shows the calculational range for the flow around three cylinders arranged together, the diameter of each cylinder (D = 10 mm). The calculation range has the following dimensions: (200D) width, (24D) height and (70D) distance of the first cylinder from the tip to obtain the boundary layer thickness of 10 mm. The boundary conditions as follows:

(1) inlet ⟶ velocity inlet ($U\infty$=2.5 m/s).

(2) outlet ⟶ pressure outlet=0-gauge pressure.

(3) no-slip on the surface cylinder.

(4) wall up & down ⟶ symmetry.

The drag and lift coefficients can be defined by the following equations:

$$CD = \frac{FD}{0.5\, \rho\, U\infty^{2}\, A} \quad (4)$$

$$CL = \frac{FL}{0.5\, \rho\, U\infty^{\,2}\, A} \quad (5)$$

3. Validation (CFD)

The results were compared by simulation of the pressure distribution (Cp) around a cylinder in the free flow region and at the Reynolds number (Re = 200), with other research results, such as the researcher Rajani [14] and others, the researcher D. S. K. Raddy [9] and others, the researcher A. Thom [15] and the researcher Mohammed & Ammar [16] as shown in Fig. 2, where the comparison results show a great convergence between them.

4. Results and Discussion

4.1 Velocity Distribution

Figure 3 shows the distribution of speed, when the separation ratios (L / D = 1, 1.2, 1.5) we note that there is separation simple of the first cylinder in due to the proximity of the cylinders to others, there is. it was a narrow, long, low-speed wake area behind the third cylinder as show Fig. 3 (a,b,c). When the gap ratios (L / D = 2, 3), the vortex spreads from the first cylinder, and the wake area behind the third cylinder is small, large and has higher speed compared to the previous cases as show Fig. 3 (d,e). However, when the separation ratio (L / D = 45) the cylinders behave as if they were single and independent cylinders due to the large distance between the cylinders as show Fig. 3 (f).

4.2 Distribution of the pressure coefficient, stagnation and separation points on cylinders

The pressure coefficient can be defined as the ratio between the static pressure and the dynamic pressure and is a dimensionless value [17]. Fig. 4 shows the distribution of the coefficient of the pressure, when the cylinders are in a free environment, and for all the separation ratios of (L / D), the values of the pressure coefficient of the first cylinder are larger than those of the second, second and third cylinders because the first cylinder was placed facing the free flow while the second and third cylinders were placed in the watch area of the first cylinder, as shown in Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10,and Fig. 11. Regarding the stagnation angles, the stagnation angle of the first cylinder is zero because the first cylinder is located in front of the free flow, while the stagnation angle of the second and third cylinders is greater than l. The angle of the stagnation points of the first cylinder, as shown in Table (1). The highest value of the pressure coefficient was at the stagnation point. We also note that separation point angles for the first cylinder at all camber ratios (L/D) were between (83°-93°).

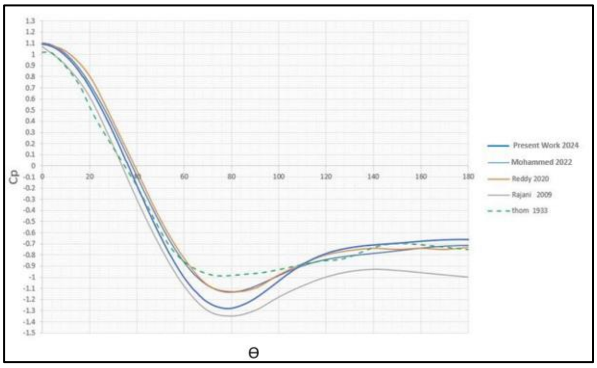

Fig. 2. Comparison of the distribution of the coefficient of the pressure (Cp) with angle (θ) of the current study 2024, researcher Mohammad 2022, the researcher D. S. K. Raddy 2020, the researcher Rajani 2009, and the researcher A. Thom 1933.

Table 1. Shows the stagnation and separation points for three cylinders.

G/D=∞	L /D= 1	L /D= 1.2	L /D= 1.5	L /D= 2	L /D= 3	L /D= 45
Stagnation angle of the first cylinder	1.3°	0°	-0.5°	-0.5°	0°	0°
Stagnation angle of the second cylinder	120.4°	74.2°	-66.6°	68.3°	67.9°	-26.3°
Stagnation angle of the third cylinder	62.4 °	-71.6°	65.2°	-39°	-55.3°	-22.2°
Separation angle of the first cylinder	92.8°	89.2°	83.7°	86°	84.2°	87.3°

4.3 Vortex shedding

In fluid dynamics, an eddy can be defined as a region in a fluid in which the flow turns into a straight line or curve around the axis line. Fig. 5 shows the shedding vortices, when the separation ratios (L / D = 1, 1.2, 1.5) we notice slippage simple of the vortices from the first cylinder due to the proximity of the cylinders to the other as show Fig. 5 (a,b,c), when the separation ratio (L / D = 2, 3), the vortex spreads from the first cylinder as show Fig. 5 (d,e), when the separation ratio (L / D = 45), the vortex spreads from each cylinder as show Fig. 5 (f).

4.4 Drag and Lift Coefficients

Figure 12 shows the drag coefficient values for all separation ratios (L / D = 1, 1.2, 1.5, 2, 3, 45), where the value of the drag coefficient for the first cylinder is positive and greater than the value of drag coefficients. for the second and third cylinders because the first cylinder was placed in front of the free flow, while the second and third cylinders were placed in the low-pressure area of the cylinder first, the values of the drag coefficient for second cylinder are less because of not placed in front of the free flow and there is no waking area behind it as in the third cylinder.

When the separation ratio (L / D = 45), it is found that the drag coefficient value for all three cylinders is positive because of the space between the cylinders, which makes the effect of low pressure between them.

Figure 13 also shows the lift coefficient values for all separation ratios (L / D), because the lift coefficient values fluctuate between positive and negative and are close to zero, due to pressure fluctuations and of the turbulent separation effect.

5. Conclusions

In the speed distribution, we observe that when the separation ratios (L / D = 1, 1.2, 1.5), the wake area behind the third cylinder is narrow, long and has low speed, because there is a vortex separation simple. When the gap ratios (L / D = 2, 3), the wake area behind the third cylinder is small, large and has a higher speed compared to the case when the gap ratios (L / D = 1, 1 ,2, 1,5), because the separation of the vortex of the first cylinder.

Also, in the distribution of the speed we noticed that when the separation ratio (L / D = 45), the cylinders behave as if they were single and independent cylinders due to the large distance of the cylinders from each other of the other.

The pressure coefficient values for all separation ratios (L / D) for the first cylinder are greater than the pressure coefficient values of the second and third cylinders, because the first cylinder was placed in front of the flow free, while the second and third cylinder. they were placed in the watch area of the first cylinder.

The angle of the stagnation points for all separation ratios (L / D) of the second and third cylinders is greater than the angle of the stagnation point of the first cylinder, the angle of the stagnation point of the first cylinder is zero because the first cylinder has been placed front the free flow.

The value of the drag coefficient for all separation ratios (L / D) for the first cylinder is positive and greater than the value of the drag coefficient for the second and third cylinders because the first cylinder was placed against 'to the free flow, while the second. and third cylinders were placed. in the low-pressure area of the first cylinder the values of the drag coefficient for second cylinder are less because of not placed in front of the free flow and there is no waking area behind it as in the third cylinder.

The value of the drag coefficient when the pitch ratio (L/D = 45) of the three cylinders is positive is due to the space ratio between the cylinders, which makes the low pressure effect between them.

The lift coefficient values for all separation ratios (L/D) fluctuate between positive and negative and are close to zero, due to pressure fluctuations and the vortex shedding effect.

6. Suggestions For Future Action

1. A theoretical study of three cylinders equal diameter in a zigzag arrangement with different angles.
2. A theoretical study of three unequal cylinders is placed in a synonym.

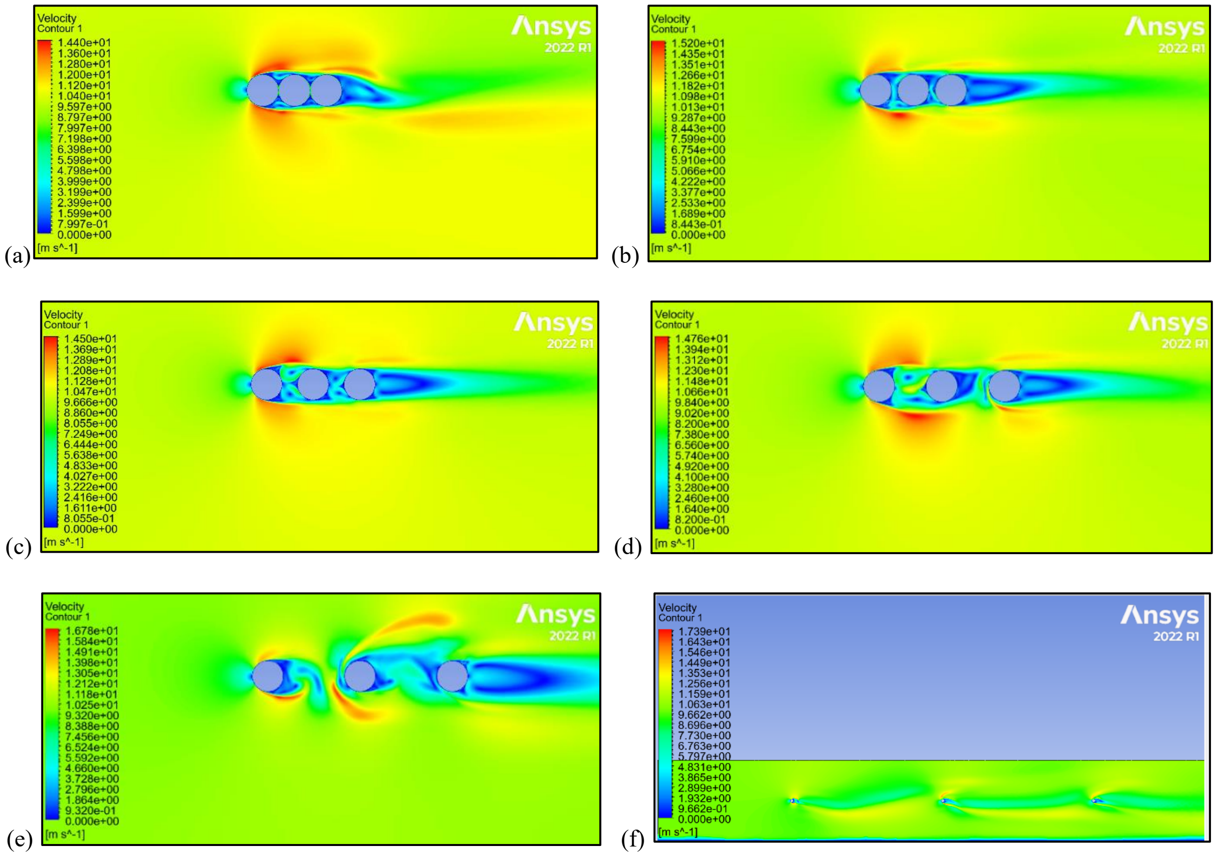

Fig. 3. Velocity contour at ratio (1 ≤ L/D ≤ 45).

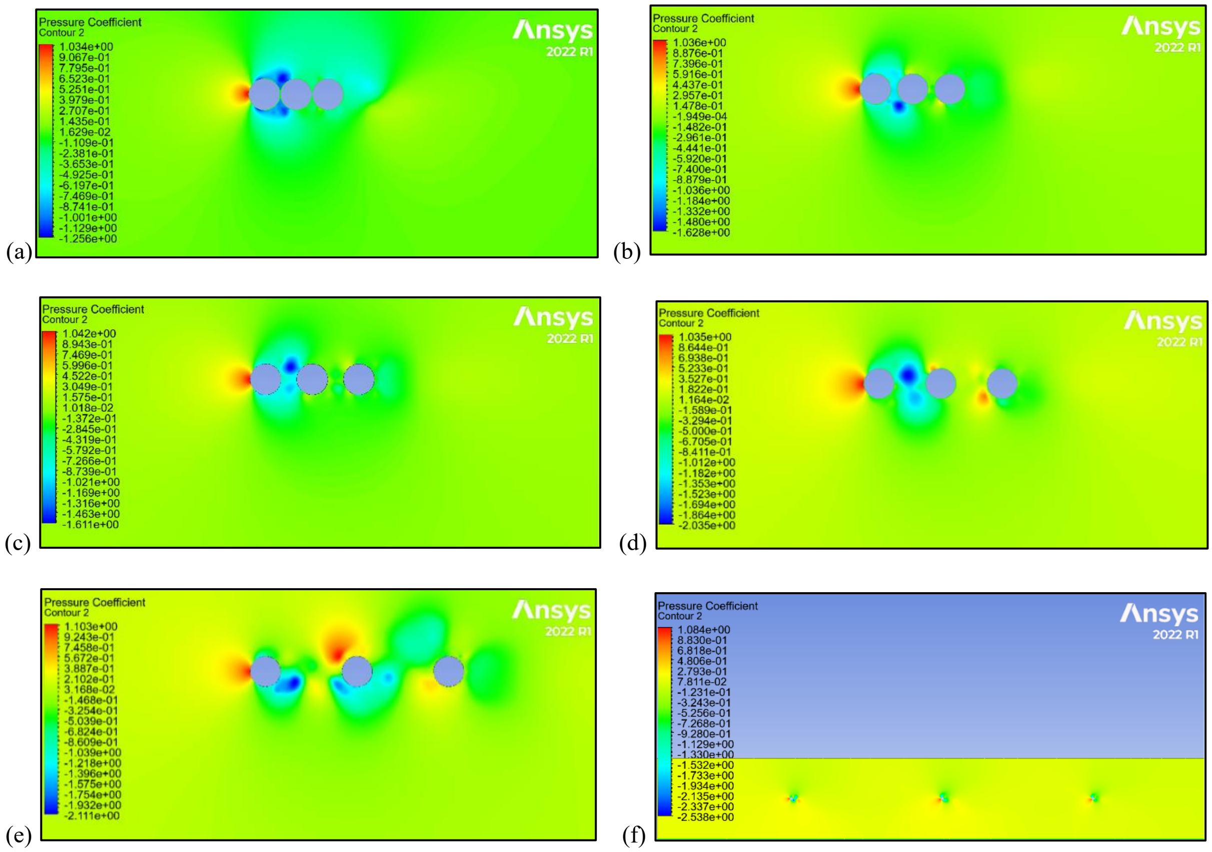

Fig. 4. Pressure Coefficient contour at ratio (1 ≤ L/D ≤ 45).

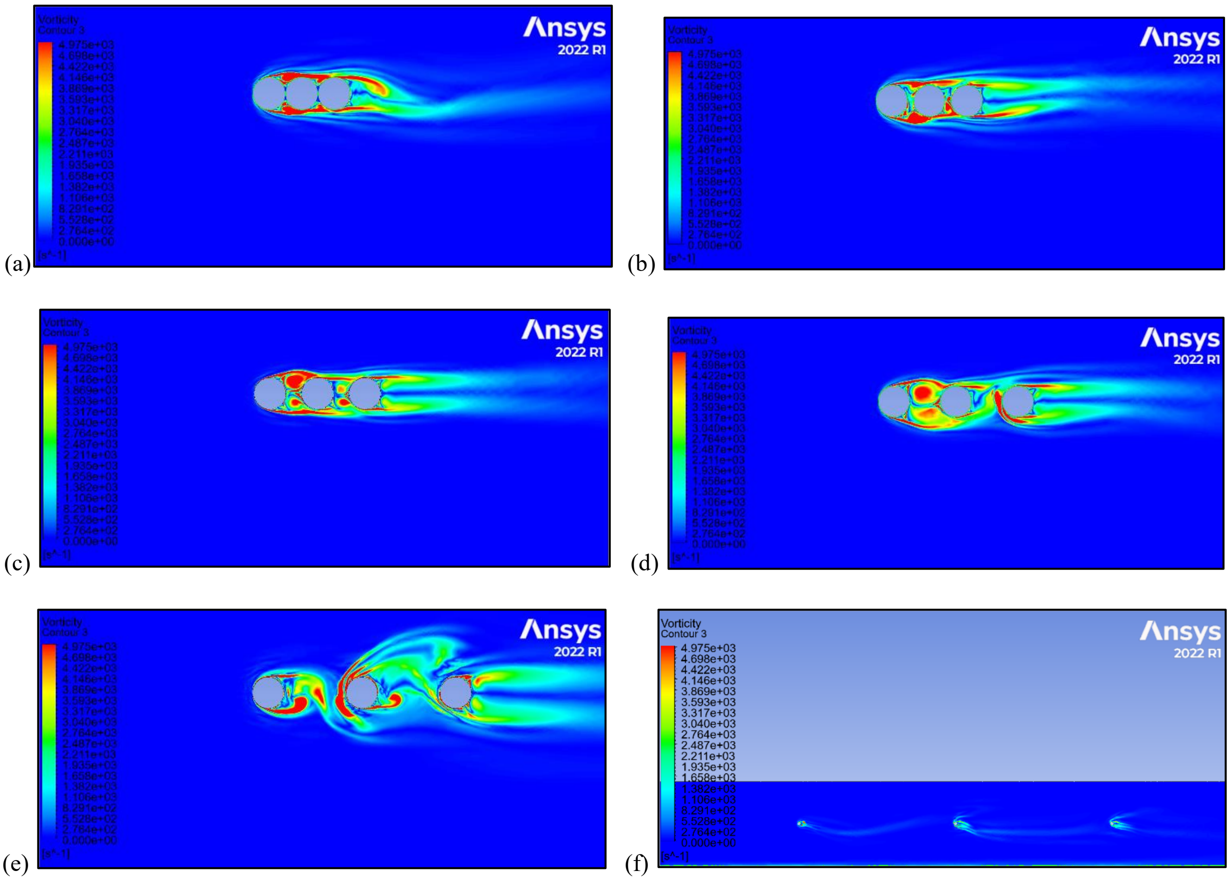

Fig. 5. Vorticity contour at ratio (1 ≤ L /D ≤ 45).

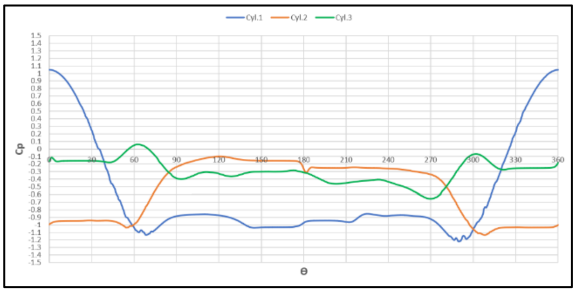

Fig. 6. Shows the relationship of the pressure coefficient (Cp) with the angle(Θ) for the three cylinders at (L/D=1).

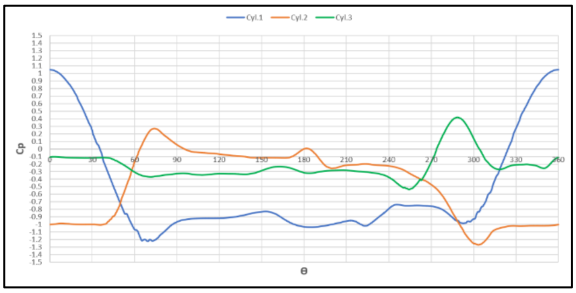

Fig. 7. Shows the relationship of the pressure coefficient (Cp) with the angle(Θ) for the three cylinders at (L/D=1.2).

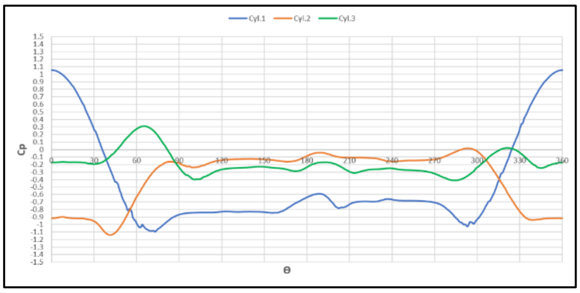

Fig. 8. Shows the relationship of the pressure coefficient (Cp) with the angle(Θ) for the three cylinders at (L/D=1.5).

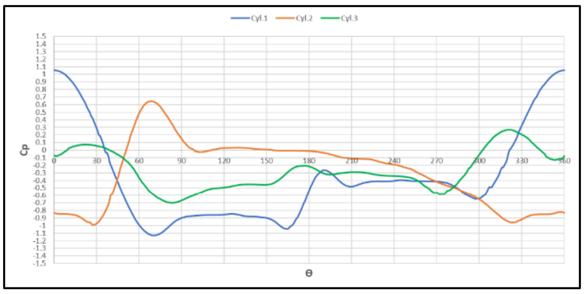

Fig. 9. Shows the relationship of the coefficient of the pressure (Cp) with the angle(Θ) for the three cylinders at (L/D=2).

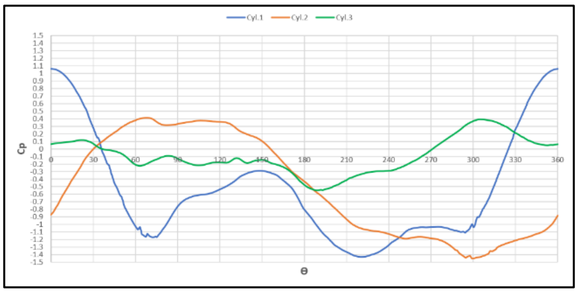

Fig. 10. Shows the relationship of the pressure coefficient (Cp) with the angle(Θ) for the three cylinders at (L/D=3).

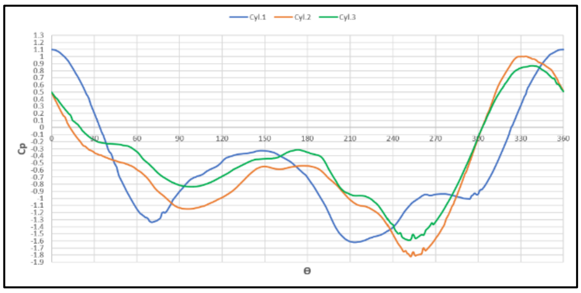

Fig. 11. Shows the relationship of the pressure coefficient (Cp) with the angle(Θ) for the three cylinders at (L/D=45).

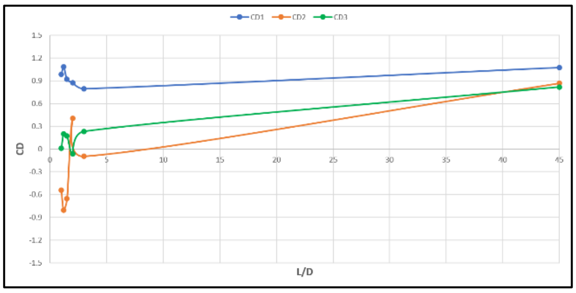

Fig. 12. Shows the coefficient of the drag for the three cylinders for all spacing ratios (L/D).

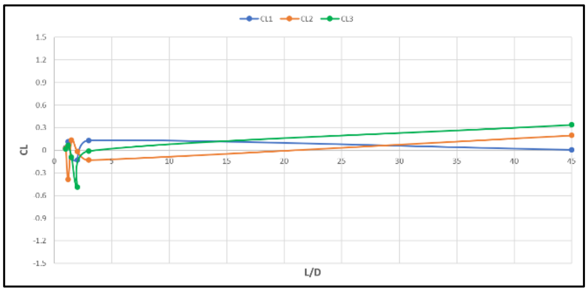

Fig. 13. Shows the lift coefficient for the three cylinders for all spacing ratios (L/D).

References

[1] H. H. Ahmed, "Heat transfer characteristics in a heat pipe using water-hydrocarbon mixture as a working fluid," *Al-Rafidain Eng. J.*, vol. 20, no. 3, pp. 128–137, 2012.

[2] C. B. Kartik, S. K. Sinha, and S. K. Choudhury, "Experimental and numerical analysis of different aerodynamic properties of circular cylinder," *Int. Res. J. Eng. Technol. (IRJET)*, vol. 3, no. 9, pp. 1112–1117, 2016.

[3] H. A. Son, S. Lee, and J. Lee, "Numerical analysis of drag force acting on 2D cylinder immersed in accelerated flow," *Water*, vol. 12, no. 6, pp. 2073–4441, 2020.

[4] B. G. Dehkordi, H. S. Moghaddam, and H. H. Jafari, "Numerical simulation of flow over two circular cylinders in tandem arrangement," *J. Hydrodyn.*, vol. 23, pp. 114–126, 2011.

[5] [5] H. X. Hu, C. B. Liu, H. Z. Hu, and Y. G. Zheng, "Three-dimensional numerical simulation of the flow around two cylinders at supercritical Reynolds number," *Fluid Dyn. Res.*, vol. 45, no. 5, 2013.

[6] Y. Wang, "Vortex shedding characteristics of flow past two different diameters cylinders in tandem arrangement at low Reynolds number," in *Proc. Int. Conf. Educ., Manage., Commerce Soc.*, 2015, pp. 695–699.

[7] P. R. F. Teixeira and E. Didier, "Numerical simulation of flow interaction between stationary and downstream elastically mounted cylinders in tandem at low Reynolds numbers," *J. Braz. Soc. Mech. Sci. Eng.*, vol. 39, no. 8, pp. 801–811, 2017.

[8] P. Sooraj, M. H. Khan, A. Sharma, and A. Agrawal, "Wake analysis and regimes for flow around three side-by-side cylinders," *Exp. Therm. Fluid Sci.*, vol. 104, pp. 76–88, 2019.

[9] D. S. K. Raddy, R. Iyer, K. Luthra, A. Rana, and P. Kumar, "Numerical investigation of flow field over four in-line circular cylinders for different spacing ratio," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 912, no. 4, 2020.

[10] X. Liu, H. Jiang, S. Wang, X. Liu, and Q. Yang, "Experimental study on fluctuating aerodynamic force and wind pressure distribution characteristics of three circular cylinders arranged inline," *Exp. Therm. Fluid Sci.*, vol. 146, p. 110908, 2023.

[11] S. A. Ali, "Influence of inserted different ribs configuration in 2D horizontal channel on characteristics turbulent fluid flow and forced heat transfer: A numerical investigation," *J. Res. Appl. Mech. Eng.*, vol. 13, no. 1, 2025.

[12] S. A. Ali, E. S. Barrak, N. J. Alrikaby, and M. R. Hameed, "Numerical study of thermal-hydraulic performance of forced convection heat transfer in dimple surface pipe with different shapes using commercial CFD code," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 125, no. 2, pp. 1–15, 2024.

[13] A. MENTEŞE and S. BAYRAKTAR, "Numerical investigation of flow over tandem and side-by-side cylinders," *Seatific*, vol. 1, no. 1, pp. 15–25, 2021.

[14] S. Rajani, R. Kandasamy, and S. Majumdar, "Numerical simulation of laminar flow past a circular cylinder," *Appl. Math. Model.*, vol. 33, no. 3, pp. 1228–1247, 2009.

[15] A. Thom, "The flow past circular cylinders at low speeds," *Proc. R. Soc. A Math. Phys. Eng. Sci.*, vol. 141, no. 845, pp. 651–669, 1933.

[16] R. T. Muhammed and A. Y. Al-Rawi, "Effect of plane boundary layer on air flow around two circular cylinders in tandem arrangement," *Int. Res. J. Innov. Eng. Technol. (IRJIET)*, vol. 6, no. 4, pp. 30–38, 2022.

[17] M. A. Waheed, "The effect of impinging jet on the flow and heat transfer from isothermal moving plate," *Al-Rafidain Eng. J.*, vol. 19, no. 6, pp. 73–83, 2011.