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# Impact of a Splitter Plate on Flow and Heat Transfer Around Circular Cylinder at Low Reynolds Numbers

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**Abstract:** In the current investigation, the effect of a splitter plate length on flow induced forces and heat transfer behavior of circular cylinder at low Reynolds numbers ($20 \le Re \le 1000$) was studied using a finite volume methodology on triangular unstructured grid. A significant reduction in the drag coefficient as well as the average Nusselt number was observed in the presence of splitter plate implying stabilization of the wake region and accordingly reduction of the vortex shedding. However, the conductive heat transfer was increased as a result of the extra heat transfer area generated by splitter plate, upon which the overall heat transfer of the system was improved.

**Key words:** Circular cylinder, splitter plate, drag reduction, heat transfer enhancement

## INTRODUCTION

Experiments and numerical simulations reported by a large number of researchers have shown that the flow and heat transfer characteristics of the separated flows downstream of circular cylinder can be greatly influenced if a splitter plate is placed along the center-line of the wake (Nakamura *et al*., 1994; Boisaubert and Texier, 1998; Kawai, 1990; Roshko, 1954). Splitter plate can alter or even suppress regular vortex shedding from cylinder and hence affect the flow-induced forces as well as the heat transfer characteristics. Roshko (1954) studied the effect of splitter plate on the wake of circular cylinder at Reynolds number of $1.54\times10^4$. This researcher showed that a splitter plate with 5D (diameter of cylinder) length suppressed the regular vortex shedding and also reduced the pressure drag of the cylinder to ~ 63% of that of the plain cylinder. However, when a 1.14D length splitter plate moved to down stream forming a gap, complicated changes in base pressure and Strouhal number of cylinder were observed. To study the influence of splitter plate length ($0 \le l_{sp} \le 7$) on drag and vortex shedding in the range ($10^4 \le Re \le 5\times10^4$), (Apelt *et al*., 1973; Apelt and West, 1975) carried out experiments with two combinations, i.e., a circular cylinder and a normal flat plate (fixed separation point)- both of which connected with a splitter plate and showed that the short splitter plate ($l_{sp} \le 2$) significantly changed the characteristics of downstream flow from the circular cylinder and from the normal plate. They, however, showed that the splitter plates longer than 2D decreased the drag and progressively slowed down the vortex shedding at $l_{sp}$ = 3D and $l_{sp}$ = 5D for the flat plate and the circular cylinder, respectively. Beyond these splitter plate lengths, it was reported that no further changes occurred, the drag coefficient remained constant and the vortex shedding decreased (Apelt *et al*., 1973; Apelt and West, 1975). Further Anderson and Szewczyk (1997) conducted experiments in an atmospheric wind tunnel to study near wake of circular cylinder at sub-critical Reynolds numbers ($2700 \le Re \le 46000$). They found that a base-mounted splitter plate appeared to be responsible for the modification of the formation region characteristics without disrupting usual Von-Karman street. Their results provide an explanation for the non-linearity in the relationship between shedding frequency and the chord length of the splitter plate. Sparrow and Kang (1985) performed experimental investigation on longitudinally finned cross flow tube banks looking at the heat transfer and pressure drop characteristics and showed that a high degree of heat transfer enhancement can be obtained by attaching integral wake splitters at the rear of the tubes. The effectiveness of a flat plate placed on the stagnation line of a square cylinder was studied upon changing the position and the width of the plate (Mahbub Alam *et al*., 2006), who reported that the optimum width of the plate for suppressing fluid forces was approximately 1/10 of the cylinder width. Tiwari *et al*. (2005) carried out a numerical simulation of flow and heat transfer around a circular cylinder with splitter plate in the channel. They found that splitter plate caused a reduction in the size of the wake zone in comparison with the wake of circular cylinder, where the narrowing of the wake zone reduced convective heat transfer but splitter plate increased the area for conduction heat transfer. Taking all together, there was an improvement in heat transfer characteristic of circular tube in comparison with plain cylinder. All these interesting

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findings led us to pursue the effect of splitter plate length on the flow induced forces, the average Nusselt number and the overall heat transfer of circular cylinder in the range of $20 \le Re \le 1000$, where this range was recruited to address such interesting impacts on cylinder using finite volume methodology with unstructured triangular grid.

## MATERIALS AND METHODS

**Problem statement:** The computational domain for the mentioned problem is shown in Fig. 1. At law Reynolds numbers ($20 \le Re \le 1000$), different chord lengths of the splitter plate

$$(0.25 \le \frac{L}{D} \le 3)$$

were considered for the study of flow structure and heat transfer behavior, where, D is cylinder diameter and L is splitter plate length. Splitter plate thickness was taken to 0.1D. Water was used as the working fluid and Prandtl number in each cell was computed using third order polynomial.

**Grid generation:** Schematic representation of 2D computational domain and the grid used was demonstrated in Fig. 1. The grid was generated by means of Watson's incremental algorithm that possesses a preliminary procedure for generation of an initial grid produced by the frontal approach. After construction of the final mesh, a Laplace filter was used to smooth the distribution of the grid points. This latter method were shown to involve movement of each node to the central area of the neighboring cells (Thompson *et al*., 1999).

**Governing equations and solution algorithm:** The two dimensional laminar incompressible equations of continuity, Navier-Stokes and energy were used for simulation of flow and heat transfer of circular cylinder with a splitter plate. Pressure field obtained by artificial compressibility technique (Chorin, 1976). We employed Jameson's cell centered five stage time-stepping scheme for unstructured grid with convergence acceleration techniques such as local time stepping and implicit residual smoothing (Jameson, 1986). Governing equations in non-dimensional form were as follow:

$$\frac{\partial W}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}=\frac{\partial R}{\partial x}+\frac{\partial S}{\partial y} \tag{1}$$

$$W=\begin{Bmatrix}P\\u\\v\\\theta\end{Bmatrix}\quad F=\begin{Bmatrix}\beta^2 u\\u^2+P\\uv\\u\theta\end{Bmatrix}\quad G=\begin{Bmatrix}\beta^2 v\\uv\\v^2+P\\v\theta\end{Bmatrix}$$

$$R=\begin{Bmatrix}0\\\frac{1}{Re_D}\frac{\partial u}{\partial x}\\\frac{1}{Re_D}\frac{\partial v}{\partial x}\\\frac{1}{Re_D Pr}(\frac{\partial \theta}{\partial x})\end{Bmatrix}\quad S=\begin{Bmatrix}0\\\frac{1}{Re_D}\frac{\partial u}{\partial y}\\\frac{1}{Re_D}\frac{\partial v}{\partial y}\\\frac{1}{Re_D Pr}(\frac{\partial \theta}{\partial y})\end{Bmatrix}$$

The variables in Eq. 1 were shown as non-dimensionalized, Eq. 2, where asterisk indicates physical variable.

$$u=\frac{u^*}{u_\infty}, v=\frac{v^*}{u_\infty}, x=\frac{x^*}{D}, y=\frac{y^*}{D}$$
$$P=\frac{P-P_\infty}{\rho u_\infty^2}, t=\frac{t^* u_\infty}{D}, \theta=\frac{T^*-T_\infty}{T_w-T_\infty} \tag{2}$$

No slip and constant temperature conditions were applied to solid boundary. The in-flow and out-flow conditions were applied to far field boundary 1 and 2-4, respectively.

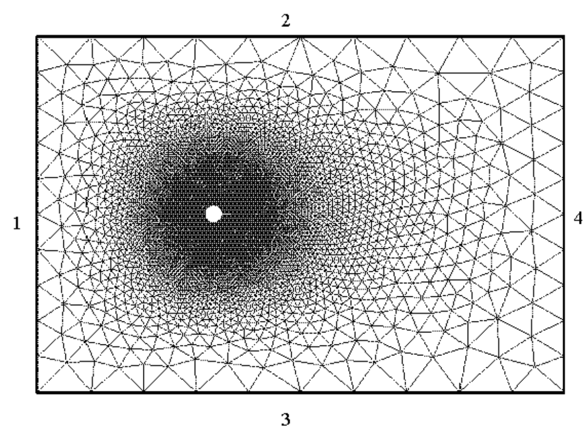


Fig. 1: Schematic representation of the computational domain and boundaries

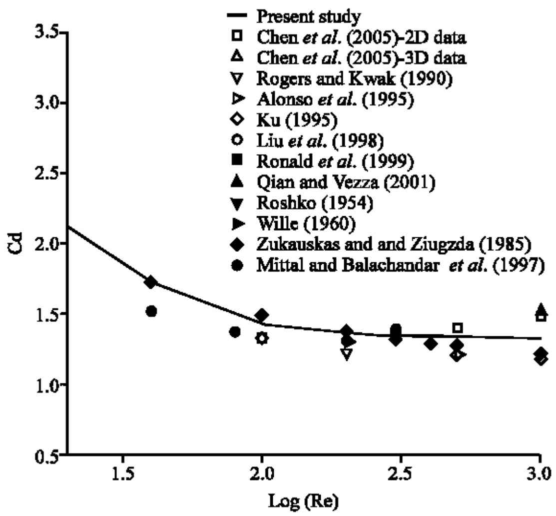


Fig. 2: Drag coefficient for plain cylinder

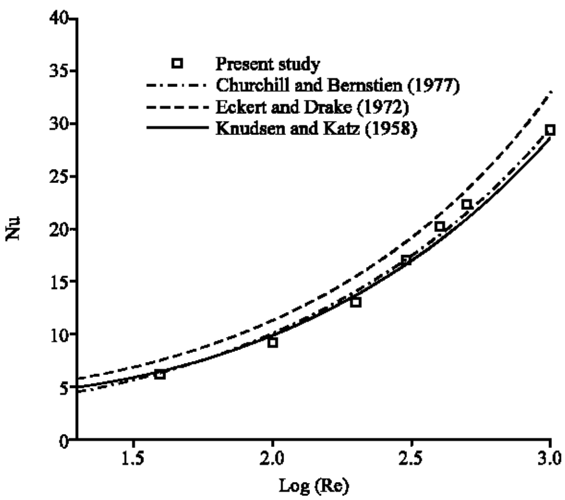


Fig. 3: The average Nusselt number for plain cylinder

Since no substantial data were available for circular cylinder with splitter plate, results of the plain cylinder were utilized for verification of the methodology used for computational assessment of the circular cylinder with splitter plate. The drag coefficient and average Nusselt number for circular cylinder were compared to the data obtained from other researchers' works as shown in Fig. 2 and 3, respectively.

## RESULTS AND DISCUSSION

**Vortex structures:** At Reynolds 40, adding a splitter plate with length

$$\frac{L}{D} \leq 0.5$$

caused slight increase in symmetric vortices length (Fig. 4A). However, when splitter plate length increased up to

$$\frac{L}{D} \leq 1,$$

two other symmetric vortices were observed (Fig. 4B). Interestingly, the longer splitter plates were found to prevent the interaction of separated shear layers with each other, as a result of which the length of bubbles decreased and the shorter vortices formed on the splitter plate surface (Fig. 4C, D).

At Reynolds 100, the shear layers were stabilized in response to the splitter length increases; where the vortex structures also displayed a streamlined status up to the 3D length of the splitter plate (Fig. 5A-C), after which the vortex shedding was completely suppressed (Fig. 5D). At Reynolds 1000, the secondary vortices were observed near the splitter surface which clearly indicates an increase in heat transfer (Fig. 6).

**Drag forces:** The effect of splitter plate length on the drag forces is shown in Fig. 7. At low Reynolds numbers ($Re \leq 40$), adding a splitter plate longer than 2D increased the friction drag (Fig. 7A). However, the pressure drag remained almost constant (Fig. 7B), at which the overall drag was increased (Fig. 7C). At the greater Reynolds numbers ($Re \geq 100$), reduced shear layers strength caused a faint reduction in the friction drag (Fig. 7A). Splitter plate streamlined the flow around the cylinder, by which the wake region was stabilized and accordingly the pressure drag was decreased (Fig. 7B). Hence, both the pressure and the friction drag were found to decrease and significant reduction was observed in total drag.

**Heat transfer characteristics:** Figure 8 shows that the average Nusselt number decreased in response to increases in the splitter length. The overall heat transfer in case of circular cylinder with splitter plate was compared to that of plain cylinder (Fig. 9). The ratio of overall heat transfer of circular tube with splitter plate to plain cylinder

$$\frac{Q}{Q_0}$$

at all Reynolds revealed significant enhancement of heat transfer, nevertheless there existed an exception in the case of

$$\frac{L}{D} = 0.25$$

which resulted in an equal heat transfer from cylinder with splitter plate and plain cylinder at Reynolds ($Re \geq 100$). As Reynolds increased up to 100, we observed reduction in the overall heat transfer ratio, in which it reached the minimum level at Reynolds 100 (Fig. 9). It appears that, at this Reynolds, the splitter plate length has no influence

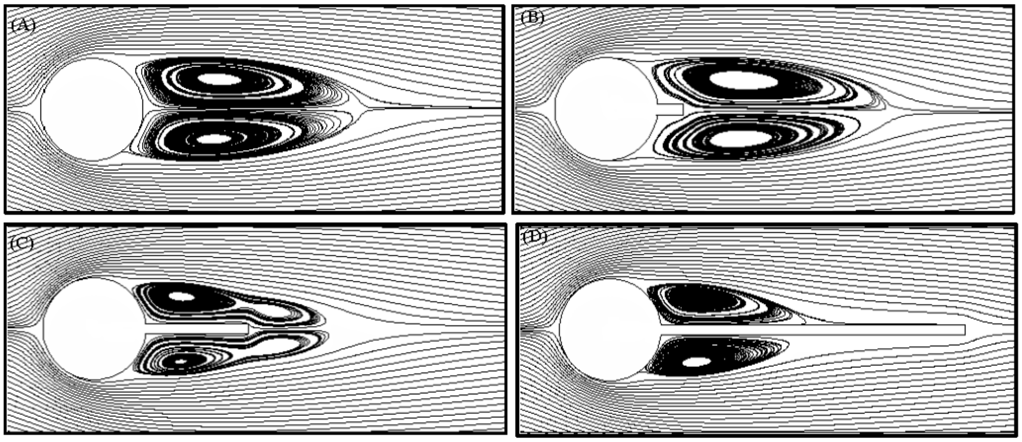


Fig. 4: Streamlines at Re = 40 for cylinder with splitter plate of length. (A): 0, (B): 0.5D, (C): D, (D): 3D

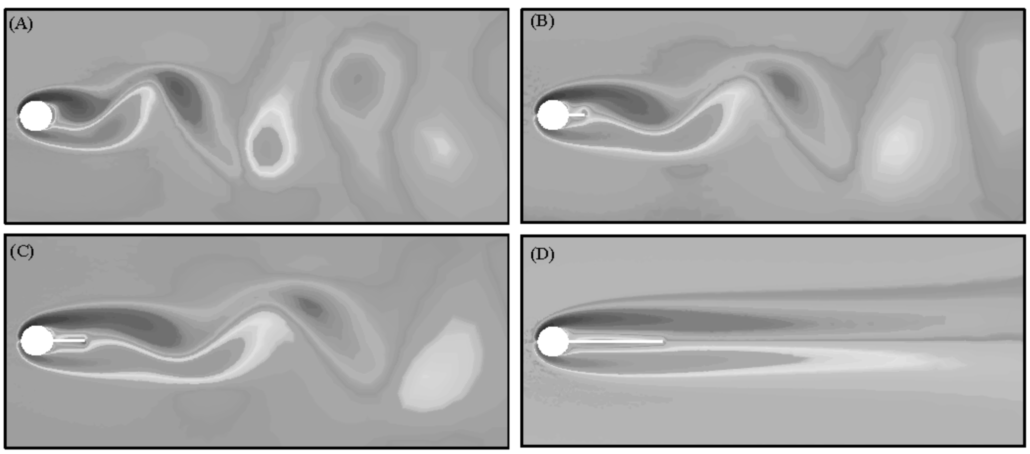


Fig. 5: Instantaneous vorticity contours at Re=100 for cylinder with splitter plate of length. (A): 0, (B): 0.5D, (C): D, (D): 3D

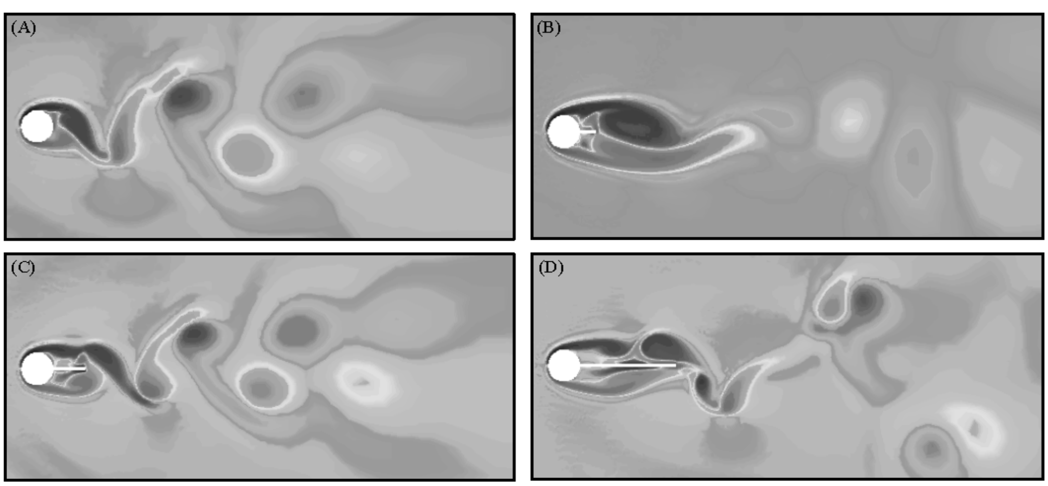


Fig. 6: Instantaneous vorticity contours at Re = 1000 for cylinder with splitter plate of length. (A): 0, (B): 0.5D, (C): D, (D): 3D

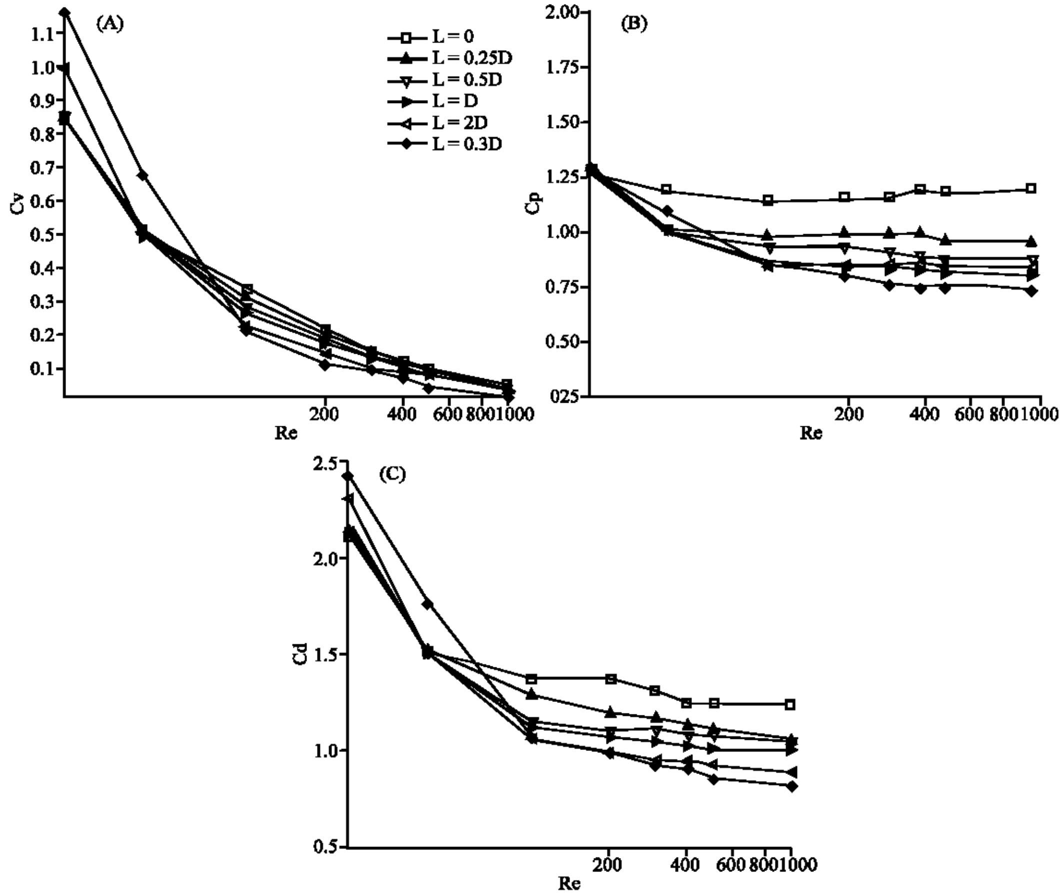


Fig. 7: Effect of splitter plate length on drag forces. (A): friction drag, (B): pressure drag, (C): overall drag. Re: Reynolds No., Cv, Cp and Cd: Coefficients of drag

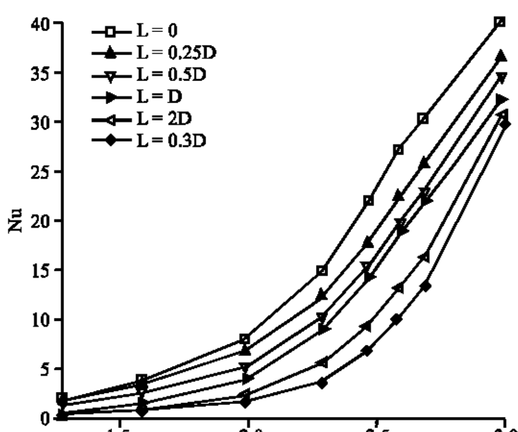


Fig. 8: Effect of splitter plate length on average Nusselt number. Re: Reynolds No., Nu: Nusselt No

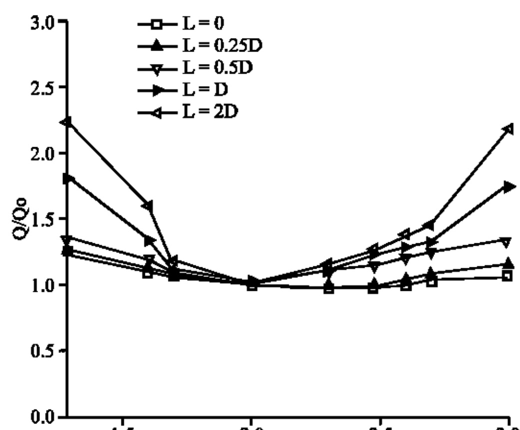


Fig. 9: Overall heat transfer ratio of circular cylinder with splitter plate to plain cylinder

on the heat transfer ratio. This clearly indicates that the resultant reduction of the convective heat transfer can cancel the increased conductive heat transfer out, at which point the heat transfer ratio is almost one. However, when Reynolds number was increased up to 1000, a progressive increase was seen in the overall heat transfer.

Upon our simulation, a reduction was seen for the size of the wake zone in comparison with the wake of a circular tube (Fig. 5, 6). Given that the reduction of the size of the wake zone caused decreased convective heat transfer from the tube surface, hence a reduction was expected to occur in the average Nusselt number as seen in our data (Fig. 8). It should be evoked that the splitter plate created a streamlined extension of the circular tube which results in an enhancement of the heat transfer from the tube surface; nonetheless it appears that such phenomenon is due to an increased conduction area. Similar findings have already been reported (Sparrow and Kang, 1985; Tiwari *et al*., 2005), whose works support our heat transfer results despite their different undertaken geometrical configurations.

## CONCLUSION

So far, particular attention has been devoted to study the impacts of the chord length of the splitter plate on the drag coefficient variations, the vortex structure and the heat transfer characteristics. Little is known about such of note heat transfer and fluid dynamics. Thus, to tackle such issue by means of numerical simulation, a splitter plate was placed on the wake centerline to optimize the characteristics of the wake downstream of a circular cylinder. We found that the splitter plate streamlined the flow around the cylinder and accordingly decreased the pressure drag causing a significant reduction in overall drag. The heat transfer was decreased from the cylinder surface, while placing the splitter plate increased the total heat transfer.

## REFERENCES


Alonso, J., L. Martinelli and A. Jameson, 1995. Multigrid unsteady Navier-Stokes calculations with aeroelastic applications. In: 33rd AIAA Aerospace Sciences Meeting and Exhibit, 9-12 January 1995, Reno, Nevada, USA.

Anderson, E.A. and A.A. Szewczyk, 1997. Effects of a splitter plate on the near wake of a circular cylinder in 2 and 3-dimensional flow configurations. Exp. Fluids, 23: 161-174.

Apelt, C.J., G.S. West and A.A. Szewczyk, 1973. The effects of wake splitter plates on the flow past a circular cylinder in the range 10^4 < R < 5*10^4. J. Fluid Mech., 61: 187-198.

Apelt, C.J. and G.S. West, 1975. The effects of wake splitter plates on bluff-body flow in the range 10^4 < R<5*10^4. J. Fluid Mech., 71: 145-160.

Boisaubert, N. and A. Texier, 1998. Effect of a splitter plate on the near-wake development of a semi-circular cylinder. Exp. Ther. Fluid Sci., 16: 100-111.

Chen, H., G.P.G. Huang and R. LeBeau, 2005. A cell-centered pressure based method for two/three-dimensional unstructured incompressible navier-stokes solver. In: 43rd AIAA Aerospace Sciences Meeting and Exhibit, 10-13 January 2005, Reno, Nevada, USA.

Chorin, A.J., 1976. A numerical method for solving incompressible viscous flow problems. J. Comput. Phys., 2: 12-26.

Churchill, S.W. and M. Bernstein, 1977. A correlating equation for forced convection from gases and liquids to a circular cylinder in cross-flow. J. Heat Trans., 99: 300-306.

Eckert, E.R.G. and R.M. Drake, 1972. Analysis of Heat and Mass Transfer. McGraw-Hill, New York.

Jameson, A., 1986. Finite-volume solution of the two dimensional euler equations on a regular triangular mesh. AIAA. J., 24: 611-618.

Kawai, H., 1990. Discrete vortex simulation for flow around a circular cylinder with a splitter plate. J. Wind Eng. Ind. Aero., 33: 153-160.

Knudsen, J.G. and D.L. Katz, 1958. Fluid Dynamics and Heat Transfer. McGraw-Hill, New York.

Ku, H.C., 1995. Solution of flow in complex geometries by the pseudospectral element method. J. Comput. Phys., 117: 215-227.

Liu, C., X. Zheng and C.H. Sung, 1998. Preconditioned multigrid methods for unsteady incompressible flows. J. Comput. Phys., 139: 35-57.

Mahbub Alam, M., H. Sakamoto and Y. Zhou, 2006. Effect of a T-shaped plate on reduction in fluid forces on two tandem cylinders in a cross-flow. J. Wind Eng. Ind. Aero., 94: 525-551.

Mittal, R. and S. Balachandar, 1997. Inclusion of three-dimensional effects in simulations of two-dimensional bluff-body wake flows. In: ASME Fluids Engineering Division Summer Meeting, Vancouver, Canada.

Nakamura, Y., K. Hirata and K. Kashima, 1994. Galloping of a circular cylinder in the presence of a splitter plate. J. Fluids Struct., 8: 355-365.

Qian, L. and M. Vezza, 2001. A vorticity-based method for incompressible unsteady viscous flows. J. Comput. Phys., 172: 515-542.

Rogers, S.E. and D. Kwak, 1990. Upwind differencing scheme for the time-accurate incompressible Navier-Stokes equations. AIAA. J., 28: 253-262.

Ronald, J.D., H.G. Lucas and C. Fang-Jenq, 1999. Transitioning Active Flow Control to Applications. Norfolk, USA.

Roshko, A., 1954. On the wake and drag of bluff bodies. J. Aero. Sci., 22: 124-132.

Sparrow, E.M. and S.S. Kang, 1985. Longitudinally-finned cross-flow tube banks and their heat transfer and pressure drop characteristics. Int. J. Heat Mass Trans., 28: 339-350.

Thompson, J.F., B.K. Soni and N.P. Weatherill, 1999. Handbook of Grid Generation. CRC Press LLC, Florida.

Tiwari, S., D. Chakraborty, G. Biswas and P.K. Panigrahi, 2005. Numerical prediction of flow and heat transfer in a channel in the presence of a built-in circular tube with and without an integral wake splitter. Int. J. Heat Mass Trans., 48: 439-453.

Wille, R., 1960. Karman Vortex Streets. In: Advances in Applied Mechanics, Von Kármán, H., R. Von Mises and H.L. Dryden (Eds.). Academic Press, New York, pp: 273-287.

Zukauskas, A. and J. Ziugzda, 1985. Heat Transfer of a Cylinder in Cross Flow. Hemisphere Publishing Corp., Washington, DC.