Ain Shams Engineering Journal (2015) 6, 929–938

Ain Shams University

Ain Shams Engineering Journal

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MECHANICAL ENGINEERING

# Steady flow over triangular extended solid attached to square cylinder – A method to reduce drag

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Received 27 June 2014; revised 17 November 2014; accepted 4 January 2015
Available online 5 March 2015

**KEYWORDS**

Square cylinder;
Extended solid (thorn);
Low Reynolds number;
Local Reynolds number;
Drag reduction

**Abstract** Numerical analysis of two dimensional steady flows over a triangular extended solid (thorn) attached to square cylinder positioned at front stagnation point and at rear stagnation point separately is reported at low Reynolds number ($Re = 40$). The variation of thorn length ($l' = 0.2$, 0.4 & 0.6) & inclination angle ($\Theta = 5°$, 10°, 15° & 20°) and its effect on the drag, pressure, shear stress, boundary layer as well as on the inertia force and viscous force are of interest. There is comparatively large variation on drag when the thorn is placed at the front side instead of placing at rear. The recirculation length is remained constant by varying the length and inclination of the thorn irrespective of its position. The variation of drag is comparatively less by changing thorn inclination. It is found that the drag is minimized by 2–3% compared to square model.


## 1. Introduction

The flow around bluff bodies has been the subject of intense research, mainly having the immense application on structural design, flow induced vibration, heat exchanger tube bundle, risers in marine technology, road vehicles, buildings and bridges. Their wakes can generate large unsteady forces which have the potential to violently damage the structural integrity of the bluff body. For this reason, many methods have been proposed over the recent years to control the wake vortex dynamics with the aim of weakening the vortex shedding and reducing the amplitude of the fluctuating lift as well as the drag [1,2].

The incompressible flow past a stationary cylinder is a very important problem in fluid mechanics. The vast majority of these studies have been carried out for the flow past a circular cylinder and square cylinder. When the different shaped cylinders are exposed to cross flow the separation takes places from the upper and lower portion of the body. Due to instability the phenomenon of vortex shedding develops known as von Karman Vortex Street.Most of the studies of flow past over cylinder were concerned with the circular cylinder case under free flow conditions. The aerodynamic behavior by flowing of fluid over a body [3], is one of the most important concerns regarding the flow behavior. The effect of aspect ratio for a circular cylinder at low Reynolds number using flow visualization has been studied [4]. They reported a discontinuity in the Strouhal number in the Reynolds number range (64–130) for an aspect ratio greater than 60. They concluded that there is a stabilization effect on the wake for a small aspect ratio

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Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2015.01.002
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## Nomenclature

| | |
|---|---|
| $B$ | blockage ratio ($D/H$) |
| $C_d$ | coefficient of drag (dimensionless) |
| $C_L$ | coefficient of lift (dimensionless) |
| $C_p$ | pressure coefficient (dimensionless) |
| $C_f$ | skin friction coefficient |
| $D$ | width of the square cylinder (m) |
| $F_D$ | drag force acting on the cylinder (N/m) |
| $F_L$ | lift force acting on the cylinder (N/m) |
| $L_r$ | recirculation length (m) |
| $L_d$ | downstream face distance of the inlet from the cylinder center (m) |
| $L_u$ | upstream face distance of the inlet from the cylinder center (m) |
| $L$ | length of thorn (m) |
| $l'$ | nondimensional thorn length ($L/D$) |
| $Re$ | Reynolds number ($=\frac{\rho U_\infty D}{\mu}$) (dimensionless) |
| $Re_x$ | local Reynolds number at horizontal axis ($x$) $\left(Re_X = \frac{\rho \cdot u_x \cdot X}{\mu}\right)$ |
| $Re_y$ | local Reynolds number at vertical axis ($y$) $\left(\mathrm{Re}_Y = \frac{\rho \cdot v_Y \cdot Y}{\mu}\right)$ |
| $U_\infty$ | free stream velocity (m/s) |
| $x$, $y$ | cartesian coordinates |
| $p_\infty$ | free stream pressure |
| $u$, $v$ | velocity components in $x$ and $y$ directions (m/s) |

*Greek symbols*

| | |
|---|---|
| $\Theta$ | triangular thorn angle |
| $\rho$ | density |
| $\delta$ | boundary layer thickness |

*Subscript*

| | |
|---|---|
| $\infty$ | free stream |

cylinder & the wake width increases with a reduction in aspect ratio. An experimental investigation [5] of flow Past a Square Cylinder at an Angle of Incidence for four cylinder orientation angle (0°, 22.5°, 30°, and 45°) and two aspect ratios (AR = 16 and 28) is conducted. A minimum in the time-averaged drag coefficient and maximum Strouhal number are seen at 22.5° reported. Therefore a remarkable drag reduction is found by changing the orientation of the cylinder. Based on a combination of numerical, theoretical and experimental studies, different flow regimes for the square cylinder have been identified in the literature depending upon the value of the Reynolds number [6–11]. The main flow regimes reported to date are as follows: a creeping flow region in which no flow separation takes place at the surface of the cylinder ($Re \leqslant 1$). At low Reynolds numbers ($2 < Re < 60$), a closed steady recirculation region characterized by the formation of two symmetric vortices behind the bluff body is observed. The most relevant feature of the flow, at moderate values of the Reynolds number, e.g. at a Reynolds number (based on the external velocity and cylinder diameter) close to 50, is the instability of the symmetric wake and the onset of a time-periodic regime characterized by alternate vortex shedding, known as the von Karman vortex street, whose dimensionless period depends on the Reynolds number. By further increasing the Reynolds number a transition to three-dimensional flow occurs around the value 180 [12–15]. The transition from two dimensional to three dimensional occurs at a cylinder-based Reynolds number above approximately 180 (in ideal conditions the critical value is about 194) [12].

The laminar flow past a square cylinder based on two different methods: lattice-Boltzmann and finite-volume method for a fixed blockage ratio $B = 1/8$ & the Reynolds number range, $0.5 \leqslant Re \leqslant 300$, [16] with the conclusion for steady flow ($Re < 60$) excellent agreement between the lattice-Boltzmann Algorithm (LBA) and Finite Volume Method (FVM) results was found for the length of the recirculation region.

The increment of drag coefficient & Strouhal number and decrement of the root-mean-squared lift coefficient are affected by the smaller gaps of parallel wall of the domain when a circular cylinder placed centrally inside a channel [17]. The development of three-dimensional structures and the succeeding transition to turbulence occurs in the wake of a circular cylinder at Reynolds numbers $190 \leqslant Re \leqslant 330$. This regime is investigated numerically by means of a spectral element method [18]. A simple method for the numerical simulation of bluff body flows where the solid object is represented by a distributed body force in the Navier–Stokes equations is studied [19]. They concluded that the main advantage of this embedding method is that the computations can be affected on a regular Cartesian grid, without the need to fit the grid to the bluff body surfaces. The flow past finite circular cylinders for Reynolds numbers 40 and 70 were simulated by numerical solutions of the incompressible Navier–Stokes equations [20]. They have simulated the pyramidal wake and the three-dimensional von Karmen vortex street. Steady flow over a square cylinder at low Reynolds number is studied numerically using finite element method [21] and they reported for the first time, values of the laminar separation Reynolds number, $Re$s, and separation angle at $Re$s.

The methods of splitter plate [23,24] and base bleed [25] for reducing drag of bluff bodies have been successfully used. The reduction of base drag has been executed due to the increase in the formation length which results in a reduction of the suction near the base of the cylinder. A remarkable drag reduction of square cylinder at different Reynolds numbers has been found by acquainting wavy stagnation face [1]. At $Re = 40$, a 3% drag reduction has found whereas at $Re = 500$, 34% drag reduction was observed which was due to increase in drag of the nonwavy cylinder. A sufficiently high waviness is impulsively introduced resulting in the stabilization of the near wake to a time-independent state. The proposed wavyness on the square cylinder affects on the redistribution of vorticity which leads to the breakdown of the unsteady and staggered Karman