Comprehensive study of forced convection over a heated elliptical cylinder with varying angle of incidences to uniform free stream

Raghav Singhal[⋆a], Sailen Dutta[b], Jiten C. Kalita[c]

[a⋆] *Corresponding author email - raghav2016@iitg.ac.in :Department of Mathematics, Indian Institute of Technology Guwahati, Assam 781039, India*
[b] *Email - sailen.dutta@alumni.iitg.ac.in :Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Assam 781039, India*
[c] *Email - jiten@iitg.ac.in :Department of Mathematics, Indian Institute of Technology Guwahati, Assam 781039, India*

Abstract

In this paper we carry out a numerical investigation of forced convection heat transfer from a heated elliptical cylinder in a uniform free stream with angle of inclination θ°. Numerical simulations were carried out for $10 \leq Re \leq 120$, $0^{\circ} \leq \theta \leq 180^{\circ}$, and $Pr = 0.71$. Results are reported for both steady and unsteady state regime in terms of streamlines, vorticity contours, isotherms, drag and lift coefficients, Strouhal number, and Nusselt number. In the process, we also propose a novel method of computing the Nusselt number by merely gathering flow information along the normal to the ellipse boundary. The critical Re at which which flow becomes unsteady, Re_c is reported for all the values of θ considered and found to be the same for θ and $180^{\circ} - \theta$ for $0^{\circ} \leq \theta \leq 90^{\circ}$. In the steady regime, the Re at which flow separation occurs progressively decreases as θ increases. The surface averaged Nusselt number (Nu_{av}) increases with Re, whereas the drag force experienced by the cylinder decreases with Re. The transient regime is characterized by periodic vortex shedding, which is quantified by the Strouhal number (St). Vortex shedding frequency increases with Re and decreases with θ for a given Re. Nu_{av} also exhibits a time-varying oscillatory behaviour with a time period which is half the time period of vortex shedding. The amplitude of oscillation of Nu_{av} increases with θ.

Keywords: Inclined elliptic cylinder, forced convection, HOC, immersed interface, vortex shedding

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1. Introduction

Bodies immersed in fluid flow can be characterized as being streamlined or blunt/bluff, depending on its overall shape and structure. A bluff body can be defined as a body that, as a result of its shape, has separated flow over a substantial part of its surface [10]; any body, which when kept in fluid flow, the fluid does not touch the whole boundary of the object. Roshko [41] defined a bluff body as one that resulted in a wide extent of separated flow and is associated with significant drag force as well as vortex-shedding. Flow past bluff bodies is commonly found in nature and engineering applications, for instance flow past an airplane, a submarine, an automobile, or wind blowing past a high-rise building. Thus, over the years, massive research efforts have been undertaken to gain a comprehensive understanding of the fluid flow and heat transfer phenomena past bluff bodies of various cross-sectional geometries. Although much effort has been devoted to analyzing the complex flow physics and thermo-fluid transport phenomenon for a variety of cross-sections (circular, rectangular, square, and elliptical), most of the literature deals with circular geometry. A thorough review of this topic can be found in the works of Williamson [54], and the books of Zdravkovich [56, 57].

It is well known that, in general, beyond a critical Reynolds number flow around slender cylindrical bodies exhibits periodic vortex shedding as a result of the Bénard-von Kármán instability which then leads to alternate vortex structures known as the von Kármán vortex street. This phenomena is responsible for fluctuating forces on the body that may cause structural vibrations, acoustic noise emissions, and at times, resonance, which would trigger the failure of structures [28]. Examples of such cylindrical structures in engineering applications include skyscrapers, towering structures, long-spanned bridges, and wires. The frequency associated with the