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Experimental study of flow through a cluster of three equally spaced cylinders

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Abstract

Flow through a cluster consisting of three equally spaced circular cylinders was studied experimentally. The spacing ratio between the cylinders was $P/D = 1.35$ and the operating Reynolds number was 2.1×10^3. Experiments were performed using flow visualization, particle image velocimetry, and laser Doppler velocimetry for a range of cluster orientation angles ($0° \leq \alpha \leq 60°$). For all cluster orientations, the results show large scale wake vortex shedding about five cylinder diameters downstream of the cluster. The large scale shedding frequency, when scaled by the projected height of the cluster, is equal to that of a single cylinder with equivalent diameter. For all cluster orientations, except $\alpha = 60°$, the wake is asymmetric. Jets forming between the cylinders lead to the formation of two distinct wake regions: narrow and wide wakes behind the cluster. For $\alpha = 0°$, a bi-stable wake regime is present in which the jet flow can be directed towards either of the two downstream cylinders, with no intermittent switching between the two wake configurations. For $\alpha = 60°$, the wake is symmetric about the mid-plane of the cluster, with narrow wakes behind the two upstream cylinders and a wide wake behind the downstream cylinder. For all orientations, small scale vortices form in the narrow wake and combine to produce large scale structures downstream. The results provide quantitative insight into the development of coherent structures in the near wake and their role in the formation of dominant vortices shed downstream of the cluster.

Keywords: Triangular cluster of cylinders; Vortex shedding; Turbulent wake; Vortex interactions; PIV; POD

1. Introduction

Interaction between fluid flow and cylindrical bodies is seen in multiple engineering applications. Some examples of these applications are heat exchangers, support structures, and aircraft landing gears. Understanding the flow physics for such geometries is important for the design of their system. Therefore, there are numerous investigations on flow over uniform single circular cylinders (e.g., [1–3]). Many of the previous studies focused on the vortex shedding phenomenon, which results in periodic loading [4], can produce noise emissions [3], and influences convective heat transfer [5]. Previous studies have shown that vortex shedding characteristics are impacted by such parameters as Reynolds number ($Re_D = \rho U_0 D/\mu$) [3, 6], free-stream turbulence [7, 8], and surface roughness [8].

Modern engineering applications usually involve fluid flow interaction with multiple cylinders. For example, flow through tube bundles in heat exchangers, clusters of support structures, cooling towers, and chimney stacks. Previous studies considered various relevant configurations, including dual cylinders [9, 10], cluster of three cylinders [11–14], square configuration of four cylinder clusters [15], and multi-cylinder arrays [16, 17]. For such cases, in addition to the Reynolds number, free-stream turbulence, and surface roughness, the spacing between the cylinders and flow orientation relative to the cluster also govern the flow regime. In comparison to studies on flow over single cylinders and dual cylinder arrangements, there are a limited number of studies on flows over cylinder clusters (e.g., three and four cylinders) and quantitative description of wake development for such geometries is lacking.

The present investigation focuses on cross-flow over a triangular cluster of three equispaced cylinders (Figure 1). The resulting flow development is known to involve complex vortex interactions and multiple frequency-centered activities in the cluster wake [11–14]. The previous investigations have shown that wake vortex shedding characteristics are governed primarily by the spacing between the cylinders (P/D), cluster orientation relative to the flow (α), and Re_D. Moreover, specific combination of these parameters can lead to the