Three-dimensional vortex flow near the endwall of a short cylinder in crossflow: Uniform-diameter circular cylinder

S.B. Chen a, S. Sanitjai b, K. Ghosh c,*, R.J. Goldstein d

a Power Systems R&D Center, Samsung Techwin Co., Ltd., Changwon-City, Kyungnam 641-717, Republic of Korea
b King Mongkut’s University of Technology, Thonburi, Thailand
c GE Global Research, Bangalore-560066, Karnataka, India
d Department of Mechanical Engineering, University of Minnesota Minneapolis, MN 55108, USA

Abstract

Flow characteristics, around a short uniform-diameter circular cylinder in crossflow, are investigated experimentally. Extensive flow visualization using oil-lampblack and smoke-wire methods have been performed. Near-wake velocity measurements have been performed using a hotwire anemometer. Complex secondary flows are observed on and around the cylinder in crossflow. Multiple vortices are observed in the horseshoe vortex system near the cylinder–endwall junction. Based on this flow visualization and local mass transfer measurement results, a six-vortex secondary flow model has been proposed.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Heat transfer from a cylinder in crossflow is of great importance in numerous energy conversion applications. Studies of short cylinder arrays in crossflows are performed to assist in the design of plate-fin-tube (PFT) heat exchangers which are widely used in the air-conditioning and automotive industries as well as in the trailing edge of high performance gas-turbine blades. Numerous investigations have been performed to study the influence of geometric parameters on the heat transfer and pressure loss in such arrays [1–3]. The heat transfer from the plates is strongly influenced by the horseshoe vortex system at the cylinder-plate junction [4,5].

A six-vortex model near the base of the cylinder was suggested by Baker [6] for an incoming laminar boundary layer. In a subsequent study [7], a four-vortex model in turbulent flow conditions was proposed. Two saddle points (signifying primary and secondary separation regions) were observed upstream of the cylinder. Langston and Boyle [8] confirmed the twin saddle points in their flow visualization study using traces from ink-dot-liquid-films. Sparrow et al. [9] used the oil-lampblack technique and also studied the heat transfer near the attached end. Goldstein and Karni [10] presented a vortex model in which a main horseshoe vortex (the size of which is approximately equal to the boundary layer thickness) sweeps the flow down along the cylindrical surface toward the endwall and a corner vortex located at the cylinder–endwall junction has an opposite direction of rotation to the main vortex. They also proposed another vortex just above the corner vortex around the front portion of a cylinder by interpreting their local mass transfer data. Other flow visualization studies could not find this new corner vortex due to its small size, but mass transfer experiments [11,12] confirmed its existence. In addition, a non-dimensional parameter, \( Re^{1/3} (d/\delta_1) \), based on the diameter of the cylinder \( d \) and the displacement thickness \( \delta_1 \) of the incoming flow has been suggested [13], which governs the formation of vortices in the symmetry plane. Lately, Ozturk et al. [14,15] conducted PIV measurements upstream and downstream of a cylinder in crossflow. The instantaneous flow data suggests that the flow structures in the upper and lower cylinder–endwall junction are non-symmetric. The primary objective of this study is to understand the flow characteristics near the endwall region of a uniform-diameter circular cylinder (UDCC) in crossflow.

2. Experimental technique

The present experiments are performed in an open-circuit, suction-type wind tunnel (Fig. 1). Two 1.6 mm diameter trips