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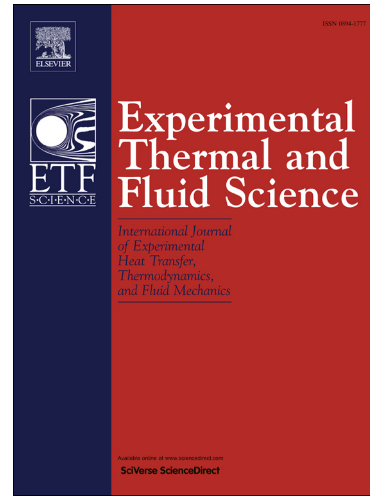

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On the Visualisation of Flow Structures Downstream of Fluttering Piezoelectric Energy Harvesters in a Tandem Configuration

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Abstract

A qualitative and quantitative investigation is carried out on two tandem, identical piezoelectric energy harvesters fluttering in a parallel, smooth flow. Previous reports revealed up to a 40% increase in power output from the downstream harvester at a certain position, though the reasons are still unknown. Here, two orthogonally positioned high-speed cameras are synchronised in time and deployed to capture smoke flow visualisation data simultaneously, in the vicinity of the harvesters. In addition, the image data from the two cameras is synchronised with real-time voltage data from the energy harvesters, permitting comparison between the image and voltage data. New results and findings are presented: 1) the occurrence of maximum voltage for these harvester types approximately coincides with the point of maximum PVDF tip velocity in the flutter cycle, 2) the Leading Edge Vortex (LEV) shed by the upstream harvester does not influence the downstream harvester, and 3) the horseshoe vortices generated by the upstream harvester act to increase the maximum PVDF tip velocity of the downstream harvester, which amplifies the power output.

Keywords: Flutter, Vortex Shedding, Energy Harvesting, Smoke Flow Visualisation, Synchronisation

1. Introduction

1.1. Background

Recently there has been considerable research into energy harvesting methods designed to power Ultra-Low Power (ULP) technologies, such as wireless sensor nodes or LED lights (Raju, 2008). These ULP devices consume very low amounts of power (i.e. in the micro- to milliwatt range), and are suited for off-grid deployment into the design space of urban-based buildings. Likewise, the energy harvesters deployed to provide power to these ULP devices also are suited for off-grid deployment, and may be fabricated to blend in with their surroundings. One idea for such an energy harvesting device was proposed by Dickson (2008), where a piezoelectric ”tree” consisted of polyvinylidene-fluoride (PVDF) ”stalks” hinged to polymeric ”leaves”. The conceptual tree could be adapted to be aesthetically pleasing and wind-induced flutter of the leaf-stalks would generate power for the ULP devices nearby.

Piezoelectric energy harvesting from a flow was first investigated by Allen & Smits (2001), where a thin membrane[1] laden with PVDF patches was placed in a flow downstream of a bluff body. The bluff body shed vortices that caused time varying pressure gradients around the membrane, leading to time varying deformations of the membrane and PVDF patches. However, power outputs were not reported. Taylor et al. (2001) conducted a very similar investigation to Allen & Smits, but their focus was on electrical subsystem optimisation for the energy capture circuit.

Classically, two types of flutter have been identified for use in flow energy harvesting using piezoelectric harvesters (Naudascher & Rockwell, 1994): 1) Movement-Induced Excitation (MIE) flutter, where an immersed membrane will begin to flutter spontaneously at the so-called *critical flutter speed*, due to the flow exciting a resonant bending instability; and 2) Externally-Induced Excitation (EIE) flutter, where time varying pressure gradients generated by vortex shedding from a discrete upstream bluff body cause dynamic deformations of an immersed membrane. The work aforementioned by Allen & Smits (2001), Taylor et al. (2001) and more recently work by Kuhl & DesJardin (2012), where two-dimensional numerical simulations were performed with a membrane and upstream bluff body, are all examples of EIE-type flutter.

MIE-type flutter has been investigated exhaustively – both fundamentally and with applications. For instance, Huang (1995) investigated palatal flutter, and discovered that the length of the immersed membrane has a dramatic effect on the critical flutter speed and flutter frequency. In a similar manner, Argentina & Mahadevan (2005) studied flag flutter and derived two-dimensional scaling laws that described the critical flutter speed and flutter frequency in a few parameters. Others have performed fundamental analytical studies on plates submerged in parallel flows (Eloy et al., 2007; Fitt & Pope, 2001). Watanabe et al. (2002a,b) undertook experimental and theoretical studies in order to help understand and mitigate paper flutter in press machines.

Li & Lipson (2009) determined the feasibility of utilising

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[1]”Membrane” in this context refers specially to a thin, highly-compliant beam.