PIV measurements of the asymmetric wake of a two dimensional heaving airfoil

Karl D. von Ellenrieder[1], Stamatios Pothos[2]

1: Dept. of Ocean Engineering, Florida Atlantic University, USA, ellenrie@fau.edu
2: Fluid Mechanics Research Instruments, TSI Inc., USA, stamatios.pothos@tsi.com

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Particle image velocimetry is used to examine the wake deflection angle of the flow behind a two dimensional heaving airfoil at a Strouhal number of 0.7 using a high resolution TSI 4MP camera. The measurements are also used to determine the virtual origin of the wake deflection.

1. Introduction

Owing to possible applications in the efficient propulsion of small-scale marine vehicles, there has been a recent surge of interest in oscillating airfoil flow. Here, the pure heaving motion of an airfoil, which oscillates at zero angle of attack in a direction perpendicular to the plane of its planform, is studied. At lower Strouhal numbers, the positions of the vortical structures in the flow are symmetrical about the mean heave line. However, starting at St $\approx$ 0.6 this symmetry is lost. Here, phase-locked PIV measurements are used to quantify this effect and to track the motion and strength of vortices shed by the oscillating airfoil.

2. Experimental Procedure

The experiments were conducted in a recirculating water channel with a 250x250x2400 mm^3 test section. The facility has a maximum flow rate of 700 mm/s. A scotch yoke mechanism, which is driven through a 10:1 gear-reducer by a servo-controlled ¼-HP DC motor, is used to provide the heaving motion of the airfoil. The airfoil is connected to the scotch yoke using clear plexiglass endplates; the endplates also limit three dimensional "end effects" at the wingtips. The airfoil has a c = 60 mm chord length and is symmetrical about its chord line with a NACA0012 cross sectional profile. The double amplitude of the airfoil heaving motion A was set such that A/c = 0.5. The oscillation frequency of the foil f was manually set via the servo motor controller.

Image acquisition is phase-locked to the motion of the airfoil using an optical limit switch and digital delay circuit. The limit switch is configured such that each time the airfoil is at the bottom of the heave cycle a trigger pulse is sent to the digital delay generator. After an appropriate delay time the delay generator outputs a signal to the PIV system to trigger image acquisition. By manual selection of the delay times the PIV image capture is precisely controlled so that data is recorded at the desired phase of the foil motion.

High resolution PIV measurements are made using a TSI PowerView Plus 2048 x 2048 px^2 4MP 12 bit camera. A 60 mm focal length lens is used to image a 200 x 200 mm^2 area of the flow at a magnification of M = 1/13.3 and f/# 2.8. The flow is seeded with 11 μm hollow glass spheres (specific gravity of 1.1 gm/cm^3) and the PIV laser light sheet illumination is provided by using a 532 nm Nd:YAG pulsed laser system. The Strouhal number St = fA/U$_\infty$ is varied by changing the oscillation frequency f of the foil; the freestream velocity U$_\infty$ and heave amplitude are held constant.

For each phase of the forcing cycle 50 velocity fields are acquired. The vector fields are determined using a CDIC deformation algorithm (Wereley & Gui 2003) combined with the Hart correlation method. The processing scheme is available in TSI's INSIGHT 3G software. This four-pass method used an interrogation region of 32x32 pixels with 75% overlap (final size). The first two passes consisted of a recursive grid to determine integer pixel displacement values while the following two passes employed the four-corner deformation grid. The vector fields were validated using standard velocity range criteria and a 3x3 local median filter. Finally, any missing vectors were interpolated using a 3x3 local mean technique. The number of spurious vectors was less than 3%.

3. Results

Data is recorded at x/c = {1, 3} chord-lengths downstream from the trailing edge of the airfoil. The resulting average velocity profiles reveal the tendency of the wake to become skewed from the line of mean position of the airfoil (i.e. to become asymmetrical about the mean position). A linear curvefit is established through the maximum value of (u - U)/U, where U is the freestream velocity, of the average velocity profile at each x/c location. This permits a "virtual origin" to be traced back to the x-axis. The angle that the line makes with the x-axis is the wake deflection angle.

The wake deflection angle was calculated from the phase-locked averages by averaging the position of maximum velocity over the complete heaving cycle at each position. The wake deflection angle and the position of the virtual origin were found to be ϕ = 6.5^o and x/c = -3.3, respectively. Hysteresis is present in the wake deflection. Between measurements, the orientation of the asymmetry reverses itself at random. While the sign of the wake deflection angle was not observed to switch while the airfoil is in motion, it seems to make its preference during start up, and then remain that way for the duration of the its motion. It also is found that as the Strouhal number is increased the wake deflection angle decreases and the virtual origin shifts upstream.