WAKE ENERGY REDISTRIBUTION DUE TO TRAILING EDGE SPANWISE PERTURBATION

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Keywords: Passive flow control, Spanwise Sinusoidal Perturbation, Near wake dynamics, POD.

1   INTRODUCTION

Passive control of vortex shedding in wakes is reliable, because of simplicity and cost effectiveness, and hence is often preferred over active control methods[1]. Examples of bluff body vortex shedding control include splitter plates[2], three dimensional disturbances[3], and surface protrusions[4]. Spanwise periodic distortion, when applied to the trailing edge and/or the leading edge of a wake generator, suppresses the vortex shedding, thereby reducing the oscillating lift and drag on bluff bodies[5, 6 and 7].

Wake flows behind two dimensional bodies are characterized by two main coherent structures, spanwise Karman vortices and streamwise vortices referred to as rolls and ribs respectively. It has been observed that the ribs wrap around the rolls, and they are interconnected. Therefore enhancing the streamwise vortices could lead to early suppression of the spanwise Karman vortices accompanied by base drag reduction.

The objective of the present investigation is to extend the application of the Spanwise Sinusoidal Perturbation (SSP) control method[7] from bluff bodies to blunt trailing edge profiled bodies with application to a family of wind turbine airfoils. Specifically, the changes in the wake structure and wake dynamics that occur when SSP is applied are investigated here. Particle Image Velocimetry (PIV) velocity measurements are performed in the base region of a profiled blunt trailing edge body. The Proper Orthogonal Decomposition (POD) is then used to identify changes in the wake structure associated with coherent energy re-distribution due to control.

2   EXPERIMENTAL SETUP

All the measurements are performed in the 0.61 m x 0.61 m x 1.21 m subsonic wind tunnel facility at the University of Wyoming Aeronautics Laboratories. This is a subsonic, open loop wind tunnel with a variable frequency driven motor capable of producing free-stream veloci-

ties of 10-50 m/s. The inlet section of the wind tunnel has a honeycomb insert and three sets of screens to break down large scale non-uniformities.

Two flat plate models with a modified elliptical leading edge for smooth flow transition of flow over the model are used. On one of these models a spanwise sinusoidal perturbation (SSP) is applied, referred to as the control case. In contrast, the other model has no SSP and will be referred to as base case A 6.25 mm wide sand strip is applied near the leading edges of these models to ensure that boundary layer is fully turbulent. For this investigation, the Reynolds number is 0.70×10^6 based on model length (L = 0.35 m), and the base height (h) of the model is 0.0254 m. The important characteristics of the flat plate model and the coordinate system are shown in Figure 1.

PIV measurements are performed in the near wake of both the control and the base case models. Measurements are performed at two different horizontal planes (y=0, and y=h/2) to study the spanwise instabilities. To study the streamwise vortices PIV measurements are performed on two different vertical planes for the no control case model and at three different vertical locations (z = 0λ, 0.25λ, and 0.50λ, where λ is the wavelength of sinusoidal perturbation) on the control case model. A LaVision PIV system with a dual frame CCD camera is used for this investigation. To perform PIV measurements, the flow is seeded using atomized oil, and the wake is illuminated using twin 50 mJ Nd: YAG lasers. The wake velocity field is determined from raw images using a cross-correlation, multi-pass, decreasing window size technique. A schematic of the location in the near wake where PIV measurements are performed relative to the flat plate model is shown in figure 1.
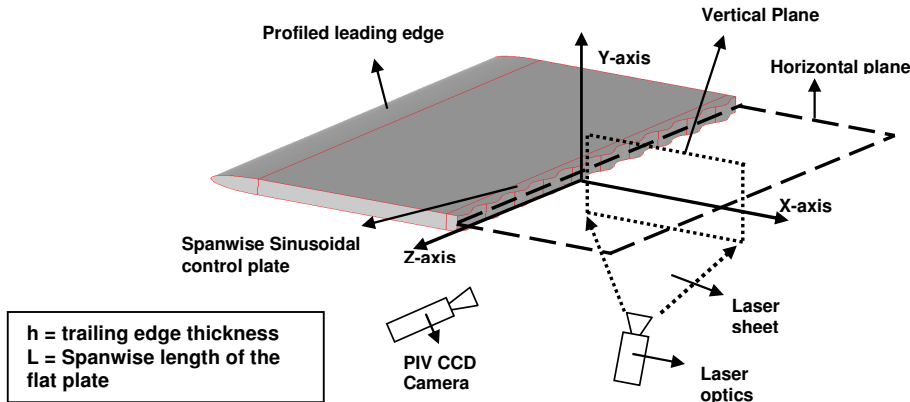

Figure 1. Flat plate model used for this investigation, along with schematic of the region in the near wake of the model imaged by the PIV system

3   PROPER ORTHOGONAL DECOMPOSITION

Proper Orthogonal Decomposition (POD) is used to study the change in near wake structures associated with span-wise sinusoidal perturbation. POD analysis yields a set of Eigenvectors or POD modes (ϕ_i) that are optimal orthogonal basis functions. These POD modes are optimized for the kinetic energy and the combination of these POD modes provide information about the spatial structures of the investigated flow field. The Eigenvalues (λ_i) associated with each of these POD modes, represent the kinetic energy captured by the corresponding POD mode. Using these POD modes the instantaneous velocity field can be then reconstructed[9] using

$$u(x, y, t) = \sum_{i=1}^{N} a_i(t)\phi_i(x, y),$$

where $a_i(t)$ is the time varying coefficient for the ith POD mode (ϕ_i) at time t. These time varying coefficients are determined by projecting the instantaneous velocity field $(u(x, y, t))$ onto the POD modes.
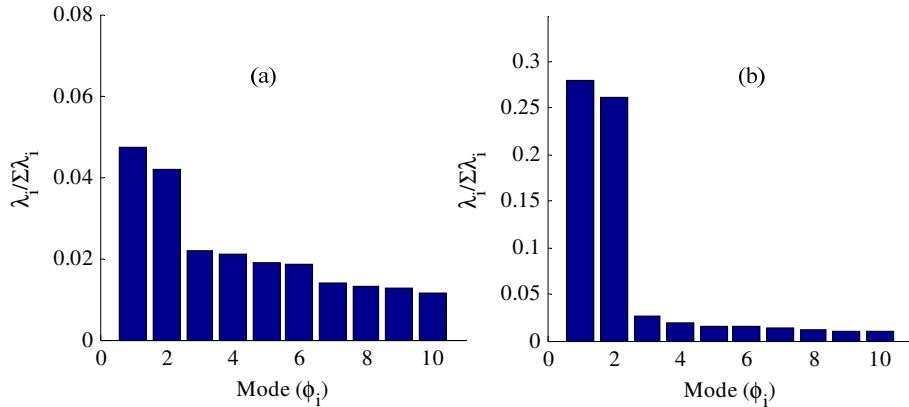
4   PRELIMINARY RESULTS

Figure 2. Relative energy captured by first ten 2-D POD modes for base case: (a) POD analysis at horizontal plane, and (b) POD analysis at vertical plane.

POD analysis is performed on the velocity field obtained from the PIV images for the investigated flow. Figures 2a and 2b show the energy captured by the first 10 POD modes in a horizontal plane and vertical plane respectively for the base case. Note that while the flow structure is dominated by the first two modes in the x-y plane, in the horizontal plane several modes are involved suggesting small scale structure with evenly distributed energy.

Figures 3a and 3b show the energy captured by the first 10 POD modes for the same planes in the SSP control case. In the horizontal plane, which captures the piercing of the streamwise vorticity, the first mode shows an increase in relative energy compared to the base case, suggesting enhancement of a predominant streamwise structure due to the SSP perturbation.
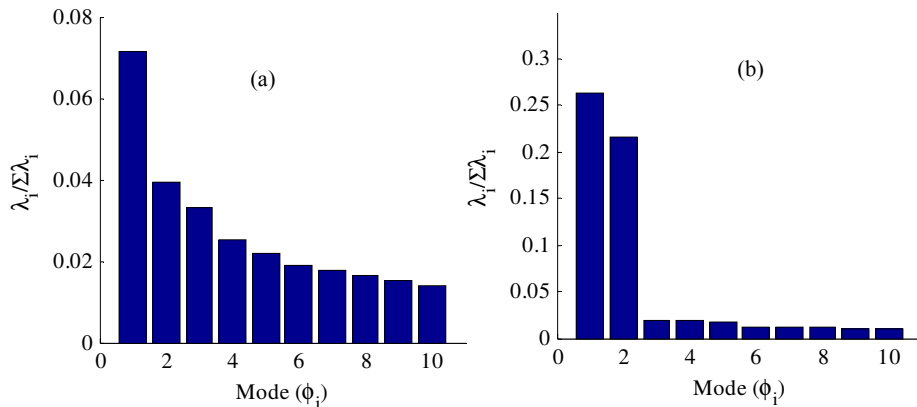

Figure 3. Relative energy captured by first ten 2-D POD modes for control case: (a) POD analysis at horizontal plane, and (b) POD analysis at vertical plane.

At the same time the vertical plane, which captures the spanwise vorticity, shows a decrease of relative energy in the first two modes compared to the base case. This behavior tends to indicate that, as expected, the SSP control strengthens the streamwise vorticity weakening the spanwise vorticity.

Figure 4(a)-(d) show the first two eigenvectors for the u and w velocity components in the horizontal plane. While the u-component is associated with the signature of the rolls, the w-component relates to the piercing of the rib-filaments through the horizontal plane. For the SSP control case mode 1 shows coherence in the w-component while the u-component is distorted.
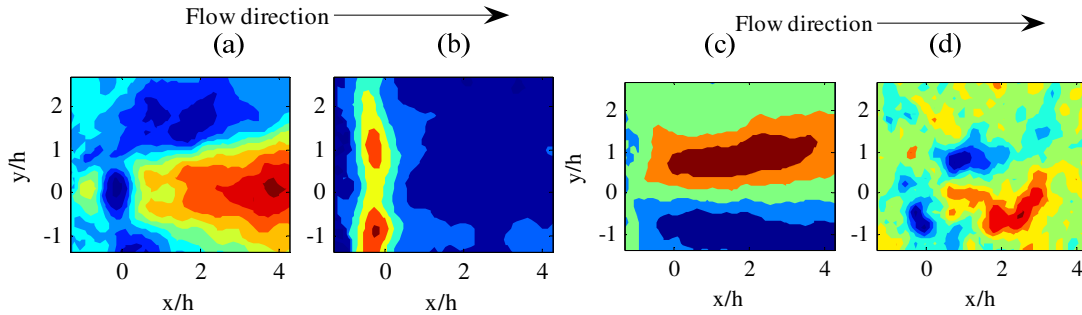

Figure 4. First two spatial POD modes in the horizontal plane for control case: (a), (b) POD mode -1 and mode-2 for x-direction velocity component, respectively, (c), and (d) POD mode-1 and 2 for z-direction velocity component, respectively.

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