STUDY ON FORCED SHEAR FLOW BY
A OSCILLATING SPOILER

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ABSTRACT: In the present paper, numerical solution of the two-dimensional unsteady Navier-Stokes equations is used to study the forced shear flow induced by a spoiler's periodical up and down oscillation on a flat plate. The paper studies the evolution of growing, shedding, merging and decaying of vortices due to the spoiler's oscillation, particularly the dependence of the forced shear flow on the reduced frequency. Results show that the reduced frequency is a key factor in controlling the growing and the shedding of vortices in the shear layer. The instantaneous streamlines and the equi-vorticity contours, as well as the surface pressure distributions, have also been investigated. Numerical results agree well with corresponding experimental ones. The study is helpful for understanding the physical mechanism of shear flow control.

KEY WORDS: shear flow, unsteady separated flow, spoiler.

1. INTRODUCTION

Recently, the problem of shear flow control is arousing great interest among researchers. Its practical application lies in the exploration of new ways to increase lift and decrease drag. The subject requires the understanding of a series of problems concerning physical mechanisms, such as the response characteristics of shear layer instability to active excitation; the deformation and twisting of shear layers; the forming, shedding, pairing and merging of vortices and the effect of turbulent boundary layer structure on drag, etc.

Most of the active excitation methods used nowadays may be of the following two types: mechanical and physical. Spoilers' oscillation on the upper surface and leading-edge flap on airfoils are examples of the former etc. The latter includes sound excitation, heat impulses and intermittent mass injection. The aim of these active excitation methods is to change the features of the shear layers and thus controlling flow separation by their effects.

Francis et al. [1] studied separation on an airfoil driven by the periodical insertion and retraction of a spoiler (Fig. 1a). Flow characteristics at several Reynolds numbers and reduced frequencies were investigated. They found a strong vortex standing behind the spoiler, which grew in size linearly with time over the first half cycle. By detailed measurements of vorticity in the separated region, they also found that the peak vorticity occurred at the time when the spoiler reached its maximum height. The measurements, both of vorticity and of pressure in the field, showed that the length of the separated region grew linearly with time after the start of spoiler insertion, until it was washed away when the spoiler was retracted. Similar experiments have been done by H. Consigny et al. [2] and M. Costes et al. [3] (Fig. 1b). Ref. [2] and Ref. [3]

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investigated the unsteady separated flows induced by a spoiler’s oscillation on an airfoil surface. The dependence of surface pressure distributions and aerodynamic coefficients on Mach number, the mean angle of inclination and amplitude of oscillation of the spoiler and the reduced frequency have been examined. D. J. Koga et al. further simplified the model used in Ref. [2] and Ref. [3], utilizing a long flat plate instead of an airfoil. Experimental results showed that the insertion of the spoiler produced a strong separated flow behind it which grew and then was shed as a travelling vortex as the spoiler was retracted. They found that the waveform of the spoiler’s oscillation had a substantial influence on the strength of the separated vortex. The lower the reduced frequency, the longer the time for accumulation of vorticity and the stronger the shed vortex. Ref. [4] also measured the position of the vortex core and found that it travelled downstream linearly with time, which is consistent with the observation of Ref. [1] concerning the growth of the reattachment length.

Control of the separated region downstream of a wedge by a flap placed in the separated region was also studied in Ref. [4] (Fig. 1c). It was found that more effective control could be obtained by oscillating the flap within the separated region. Reattachment length of separated region $x_*$ was dependent on the reduced frequency of the flap. When the reduced frequency was equal to 0.08, $x_*$ was near its minimum value, and a 50% reduction in the mean length of the separated region was achieved.

The flap length in the experiment of Ref. [4] was the same as the height of the upstream wedge inducing separation. In fact, shorter flap might also have significant influence on the separation region. This conclusion has been proved by experiments conducted by P. H. Reisenthel et al. (Fig. 1d). They found that the reattachment length of the separated region shortened with the increasing of the flap’s amplitude of oscillation. The most effective control could be realized when the flap stands just downstream of the separation point.

Based on experiments of Ref. [4] and Ref. [5], H. M. Nagib et al. made a dynamical analysis of the correlation between reattachment control and the reduced frequency. They pointed out that there exist at least two distinct mechanisms controlling flow reattachment. At low reduced frequency, the primary mechanism corresponds to the momentum exchange induced by the modulation of the separated shear layer, and leads to the periodical shedding of the separation bubble. This mechanism scales with the characteristic height of the separated region. At high reduced frequency, the dominating mechanism is the formation and shedding of vortices caused by the oscillation of the flap. This mechanism scales with the reduced frequency based on the