Boundary Layer Transition Control Using Piezo-actuators

by

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1. Introduction

Results of mostly wind-tunnel experimental research on boundary layer transition control using piezo-actuators will be presented. In transitional boundary layers, waves of various modes may be present, and some of which may lead to laminar-turbulent transition. Besides most well known Tollmien-Schlichting wave, waves such as crossflow-instability wave and streamline-curvature wave exist in a three-dimensional boundary layer, which can be found in a boundary layer of a swept wing of an aircraft. The angle and wavelength of these waves may change by the flow condition, so there is a demand to develop a device which can control waves of various angles and various wavelengths. Sensing a incoming wave should not be a major problem, so developing a device which can produce a wave that will cancel the incoming wave is the challenge.

Prior to the start of this research, we were interested in “receptivity.” We were aware that by attaching a thin tape on the flat plate surface combined with an acoustic excitation, a T-S wave or an oblique wave can be introduced into a laminar boundary layer. Though the experiment, it was found that the oscillation motion of the air near the corner of the tape, caused by the acoustic excitation, was most important. If the oscillatory motion of air, couple of microns, relative to the edge of the tape is the key, the same result should be obtained by oscillating the edge of the tape a few microns. Piezo-actuator, which is 0.3mm thick, is found to a device perfect for this purpose. So, series of experiments are carried out using piezo-actuators.

2. Results

Experimental research is carried out on a flat plate boundary layer. First, the basic features of waves generated by the piezo-actuators are checked. It is found that piezo-actuators are capable not only to generate a two-dimensional T-S wave, but can generate oblique waves of various sweep angles and two oblique waves crossing each other at various angles. The process is a “receptivity without acoustic forcing.”

As a next step, a two-dimensional T-S wave, or two oblique waves crossing each other, which are called the “target waves”, are generated upstream by a thin tape or tapes attached on the flat plate surface and acoustic forcing. The piezo-actuators are used to generate waves that will neutralize the target waves. The attempt is fairly successful although not perfect. The trouble is that the incoming wave is not necessary perfect. In some places the amplitude of velocity fluctuation is larger or smaller than the average, in other places the phase of the fluctuation is in disorder. However because, in our system, more than ten small pieces of piezo-actuators are attached to the flat plate surface side-by-side in the spanwise direction, the amplitude and the phase of each actuator can be controlled independently, a fine-tuned controlling attempt is carried out. A noticeable refinement in the wave-canceling effect can be obtained as the result of the fine-tuning.

In the experiment described above, it is found that the oblique wave of large sweep angle is difficult to neutralize. This can be partly be developed by a more serious study.
Some of the experiment is copied by a three-dimensional numerical simulation of incompressible Navier-Stokes equations. The agreement between the experimental results and the computational results is excellent. The numerical simulation provides more information such as vorticity components close to the wall. The numerical simulation research helped understand some phenomena which couldn’t be explained by the experimental data only.

3. Summary
As a result of a research on boundary layer transition control using piezo-actuators, it can be concluded that piezo-actuator is a promising device that can cancel the incoming waves even with sweep angles. The proof that the operation of the piezo-actuator device can actually delay the laminar-turbulent transition will be need as a next step.

References