Distributed TS-Wave control by means of active walls

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1. Introduction

Any body exposed to a flow, generates drag forces. In order to minimize skin friction as dominating part of this overall drag, an extended laminar boundary layer flow is favorable. Since laminar-turbulent transition involves a large increase in skin friction, even a moderate delay of transition promises significant drag reduction.

Boundary layer transition can be delayed by active and passive means. Transition on unswept two-dimensional wings is mainly caused by Tollmien-Schlichting (TS-) waves. The attenuation of these convective instabilities with a newly developed active laminarization method was investigated in wind tunnel experiments. Thereby, amplification of TS-waves is delayed by superposition with artificial counterwaves. Dynamic boundary layer stabilisation, which is also called 'active damping' has been proved as successful laminarisation method in former experiments. Due to the two-dimensional character of TS-waves in the early stages of transition, small spanwise actuation strips were suitable for the generation of counterwaves. In this study, this locally limited actuation is extended towards larger, actively driven surface areas. The method allows for extension of actuation range, and therefore, laminar flow as well as a more efficient introduction of counterwaves into the boundary layer.

2. Objectives

This study was inspired by the visco-elastic properties of dolphin's skin which is one reason for their low skin friction. Because Reynolds-number and relevant pressure forces of an aircraft are different from a swimming dolphin, drag reducing skin properties of the dolphin can not be transferred to an wind tunnel test setup by just copying material parameters. Instead, dynamic skin properties are simulated by an active deflection of the wing's surface by real-time controlled actuation. An extended 'active wall' area as part of the wing's surface was designed. A wall-mounted surface membrane is connected to compact actuation elements, integrated into the wing, at several supporting points. This setup generates travelling counterwaves.

The study answers the following questions: What is the scale of potential transition delay with an active wall? Which dynamic properties should such an active

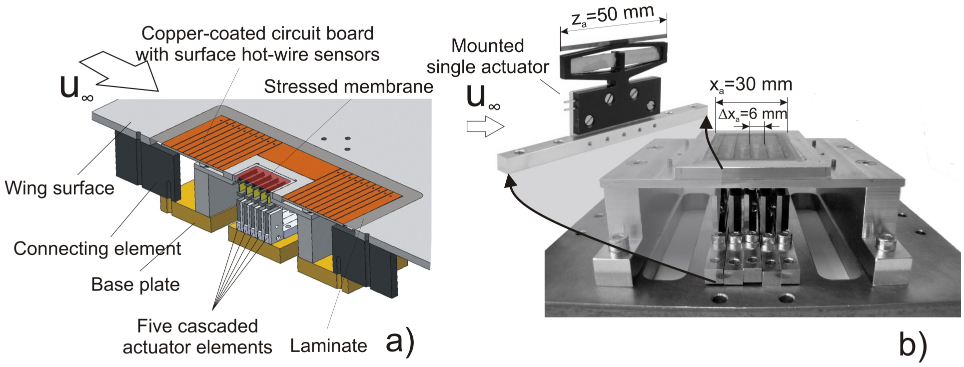

Figure 1. Active wall, driven by five streamwise actuator elements,(a) Sketch of sensor actuator set-up (b) Photo of this installation

wall have? Which parameters influence the damping behaviour? Is it possible to attenuate three-dimensional flow instabilities as well? What is the active wall's effect on skin friction at the wing?

Different arrangements of piezo-membrane actuators were investigated with arrays of highly sensitive surface flow sensors and appropriate model predictive control strategies. A symmetrical, unswept, two-dimensional wing model was used for the experiments. Chord Re-number was $Re_c \approx 10^6$.

3. Results

With an active wall, driven by five streamwise actuation elements, the onset of transition could be shifted downstream by 140 mm for a freestream velocity of $u_\infty = 24,5\ m/s$. This equals seven average TS-wave lengths or 10,8 % of chord length. The required wall deflection amplitude is 0,6 % of local boundary layer

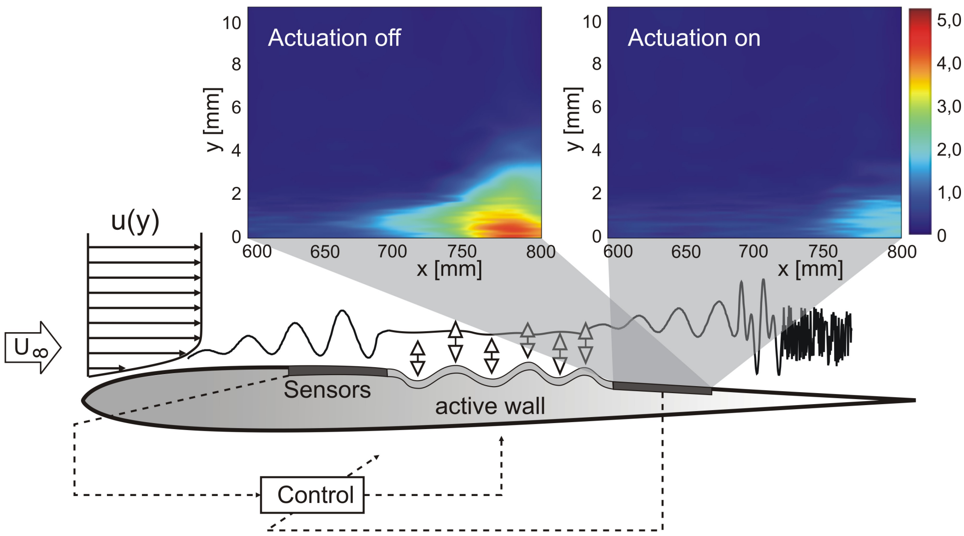

Figure 2. Fluctuations within the boundary layer with actuation off (left contour plot) and actuation on (right contour plot)

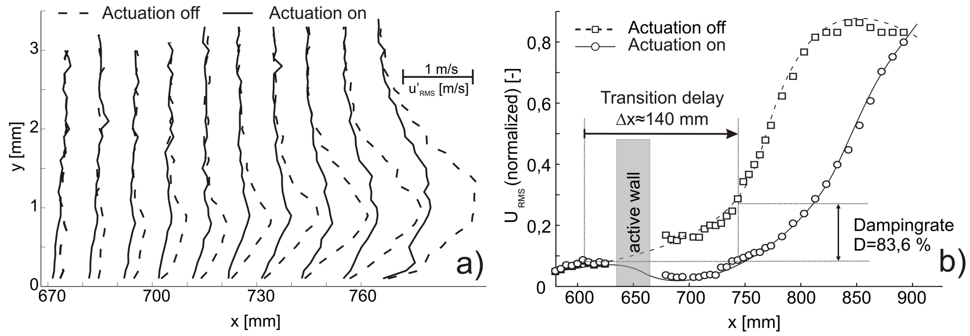

Figure 3. Boundary layer downstream of the actuated wall (a) boundary layer profile of velocitiy fluctuations, (b) Amplification of the TS-Wave and transition delay

thickness. A suitable streamwise distance between actuation elements is x=6 mm or one quarter of the average TS-length.

For the first time, natural TS-waves were attenuated by artificial, convective counterwaves which were generated on a large area. Former research concentrated on spatially limited actuation strips and / or artificially generated TS-waves.

A non-vertical wall displacement was also never tried before. An inclined actuation of 30° showed slight advantages over vertical deflection. The additional wall parallel part of deflection has an effect comparable to anisotropic properties of compliant walls, as Carpenter described it. Damping of three-dimensional flow instabilities was demonstrated as well. Spanwise differentiated actuation was used to attenuate oblique boundary layer instabilities. Additionally, the investigation of the boundary layer flow downstream of the active wall area and an efficiency estimation are presented in this study.

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