Active Cancellation of TS Instabilities in Compressible Flows Using a Closed-Loop Controller

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ABSTRACT

The delay of the laminar-turbulent transition is crucial for the reduction of the skin friction. Many active and passive methods have been investigated to delay laminar-turbulent transition. Most control techniques aim to stabilize the mean velocity profile of the boundary layer, whereas the wave-cancellation method assumes that a wavelike disturbance can be linearly cancelled by introducing another wave with a similar amplitude but difference in phase.

The natural transition process on an unswept wing, which occurs for very low freestream turbulence levels, can be divided into the following parts: Disturbances in the freestream, such as noise or vorticity, enter the boundary layer as steady or unsteady disturbances. Once the perturbations have found their way into the boundary layer and are transformed to small amplitude waves, they are either linearly damped, or frequency-selectively amplified, while propagating downstream. In their first stage of development, the traveling harmonic instabilities are mainly two-dimensional. All TS-modes grow independently, so that linear superposition with artificially generated counter waves is possible without any destructive mode coupling. In the later stage, the development becomes more and more non-linear and secondary instabilities lead to a heightened growth of three-dimensional disturbances. These three-dimensional distortions result in lambda vortices and finally in a fully turbulent boundary layer.

In principle, a single 2D-control system consists of a reference sensor where the weak TS instabilities are detected. Further downstream, a surface actuator is integrated whose signal is generated by applying an adaptive transfer function (adaptive digital filter) to the disturbance signal of the reference sensor. The filter is continuously adapted in order to minimize the signal of the error sensor located downstream. The control is performed with a digital signal processor that executes an FXLMS-adapted (filtered-x-LMS) FIR-filter which is primarily known from applications to active noise control (ANC), but was already used in low speed TS-control experiments by Baumann, Sturzebecher & Nitsche [1] and Sturzebecher & Nitsche [2].

In a first design step of the controller, experiments at a low Mach number ($M = 0.2$) have been carried out. Additionally, a perturbation actuator was positioned upstream of the reference sensor to introduce controlled mono-frequent 2D-waves into the boundary layer. The chosen perturbation frequency ($f = 2kHz$) is in the typical frequency range of natural TS instabilities at this Mach number. First results show remarkably lower amplitudes in the error sensor time traces in the case of controlled instabilities. Furthermore the $2kHz$ peak in the power spectrum is successfully damped by about 15dB. Further experiments will deal with natural TS instabilities, whereas the Mach number will be pushed up to $M = 0.5$. 
REFERENCES
