Linear and Nonlinear Receptivity to Tollmien—Schlichting Waves in Transonic Flows

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Motivation

Modern passenger airplanes operate at transonic speed. Two modes of instability are known to be important for laminar-turbulent transition on an aircraft wing: the Tollmien—Schlichting waves and Cross-Flow vortices. In this project we are concerned with the Tollonien—Schlichting waves. A distinctive feature of the cruise flight is that the level of the free-stream turbulence is extremely low, much lower than it may be achieved in a wing tunnel. Under these conditions, the laminar-turbulent transition process can be subdivided into a number of distinct stages, the first of this is the receptivity stage, where the external perturbation (such as free-stream turbulence, acoustic noise, wall roughness, wall vibrations, etc.) penetrate into the boundary layer and turn into the boundary-layer instability modes.

Research

This study is concerned with the effect of an acoustic noise on the boundary layer in transonic flows. It is based on asymptotic analysis of the compressible Navier—Stokes equations assuming that the Reynolds number tends to infinity and the free-stream Mach number tends to one. The transonic version of the triple-deck theory is used to study the generation of Tollmien—Schlichting waves by sound noise as it interacts with local roughness on the wing surface. First the linear receptivity of the boundary layer is considered. In this part of the project, it is assumed that the amplitude of the acoustic wave is very small and also the roughness height is smaller than the thickness of the viscous layer. Under these assumptions an analytic expression for the amplitude of the generated Tollmien—Schlichting wave is deduced. In the second part of the project, the roughness height is assumed to be large enough to cause local separation. In this case the solution of the receptivity problem requires numerical solution for the perturbations. The correspondent numerical code has been written, and it allows us to find the amplitude of the generated Tollmien—Schlichting wave.

Application to industry

Currently, to predict the position of the laminar-turbulent transition on an aircraft wing, the Industry relies on the e^N-method. The accuracy of the predictions can be improved if the initial amplitude of the instability mode is known. The methods developed in this project allow us to provide this information. Also they may be used for development of a control strategy to suppress generation of the instability modes in the boundary layer.