EXPERIMENTAL STUDY OF DISTRIBUTED RECEPTIVITY COEFFICIENTS AT EXCITATION OF GÖRTLER MODES BY FREE-STREAM VORTICES

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Abstract The paper is devoted to an experimental quantitative study of distributed excitation of unsteady Görtler-instability modes in a boundary layer over a concave wall by free-stream vortices (receptivity problem). Experiments are carried out in a low-turbulent wind tunnel under completely controlled disturbance conditions. Investigated receptivity mechanism is found to be rather efficient. It is able to change significantly the growth rates of Görtler vortices (in comparison with the linear-instability growth rates). Extremely difficult task of identification of distributed receptivity coefficients was solved successfully. It was found that the amplitudes of the coefficients reach their maximum values for those Görtler vortices which dimensionless spanwise scales Λ are between 250 and 500. The receptivity coefficients turned out to decrease rather quickly with the streamwise coordinate.

INTRODUCTION AND EXPRIMENTAL PROCEDURE

The study of various mechanisms of generation of Görtler modes is one of the most important practical and fundamental tasks of Görtler instability problem. This task is related to the very first stage of the laminar-turbulent transition and describes how various external (with respect to boundary layer) perturbations penetrate into the boundary layer providing initial seeds for the Görtler vortices. The present paper is devoted to experimental quantitative investigation of distributed excitation of unsteady Görtler-instability modes [1] in a boundary layer over a concave wall under the affect of free-stream vortices.

The experiments were carried out in a low-turbulence wind-tunnel T-324 of the Khristianovich Institute of Theoretical and Applied Mechanics (ITAM) of the Siberian Branch of the Russian Academy of Sciences (Novosibirsk) at the free-stream speed of 9.18 m/s. The boundary layer was developed over an experimental model representing a plate of 2.38 m long and 1 m wide with concave surface having a radius of curvature in streamwise direction of R = 8.37 m. An adjustable wall bump was installed above the concave plate in the wind-tunnel test section. The bump shape was adjusted in a way to provide the base flow with zero streamwise pressure gradient. It was shown that the base flow represented the Blasius boundary layer. The main measurements were performed by a hot-wire anemometer in a range of the streamwise coordinates, which corresponded to values of the Görtler number (based on the local boundary-layer displacement thickness δ_1) G^* = 8 to 21, approximately.

The experiments were performed under completely controlled disturbance conditions – longitudinal free-stream 3D-vortices were generated by a special disturbance source. This source represented an oscillating thin wire, equipped with a local non-uniformity. The wire was mounted in the potential flow upstream the experimental model parallel to its leading edge. The harmonic wire oscillations (occurred in the direction perpendicular to the leading edge and the free-stream velocity vector) were driven by two small stepping motors, which were controlled electronically. The oscillations generated in the flow a low-amplitude vortex street of required frequency f, which propagated downstream along the external edge of the boundary layer. Three-component hot-wire measurements have proved that the flow motions produced in the wake behind the wire non-uniformity had a rather intensive streamwise vorticity component (at spanwise sides of the non-uniformity, the vortex street remained two-dimensional one).

MAIN RESULTS

It was found that the investigated mechanism of distributed excitation of unsteady Görtler vortices is rather efficient and able to change significantly their growth rates (in comparison with the linear-instability theory). In particular, the presence of streamwise freestream vortices can convert attenuating Görtler vortices into the amplified ones.

Detailed experimental information on this mechanism was obtained in a wide range of controlled parameters. Deep, versatile processing of these data was carried out in order to obtain, for the first time, reliable quantitative values of the distributed receptivity coefficients The general approach of determination of these coefficients is similar to the one developed in paper [2] (devoted to the study of distributed generation of Tollmien-Schlichting waves). Estimation of the accuracy of solving the corresponding inverse problem by application to the data processing of various methods and hypotheses about the properties of the required receptivity functions was one of the main purposes of the study as a whole.

A general view and parameters of the unknown complex receptivity function $\overline{G}_v^d(x)$ (for each particular frequency and spanwise wavenumber) were searching by means of fitting the experimental data (amplification curves for complex amplitudes of Görtler vortices) by a relevant analytical solution of evolutionary equation. The solution represented an integral function, which included the specified unknown function $\overline{G}_v^d(x)$ (x is the streamwise coordinate). The fitting was performed by utilizing optimization toolbox of MATLAB (gradient, simplex and genetic algorithms). Complex receptivity functions were sought in one of the following forms: (*a*) constants, (*b*) exponential functions, (*c*) first-order polynomials, (*d*) hyperbolic functions or (*e*) various combinations of the functions indicated above. The investigation has shown that the functions of the form (*b*) provide a good approximation of the experimental data in the whole range of streamwise coordinates. The solution of the optimization problem was carried out by means of utilizing one of two different criteria. The unknown eigenvalues of Görtler instability modes were taken either from experiment or from theoretical calculations based on linear stability theory. It was found that the amplitudes of the receptivity coefficients reach their maximum values for those Görtler vortices which dimensionless spanwise scales Λ are between 250 and 500 and decrease rather quickly with the streamwise coordinate.

Amplitudes and phases of the distributed receptivity coefficients, as well as the features of their dependence on the problem parameters (frequency, spanwise wavenumber and streamwise coordinate) are practically independent of the fitting algorithm and depend rather weakly on the fitting criteria (Fig. 1). This result testifies in favor of reliability of the obtained experimental values in spite of the extreme complexity and ambiguity of the used mathematical procedures.

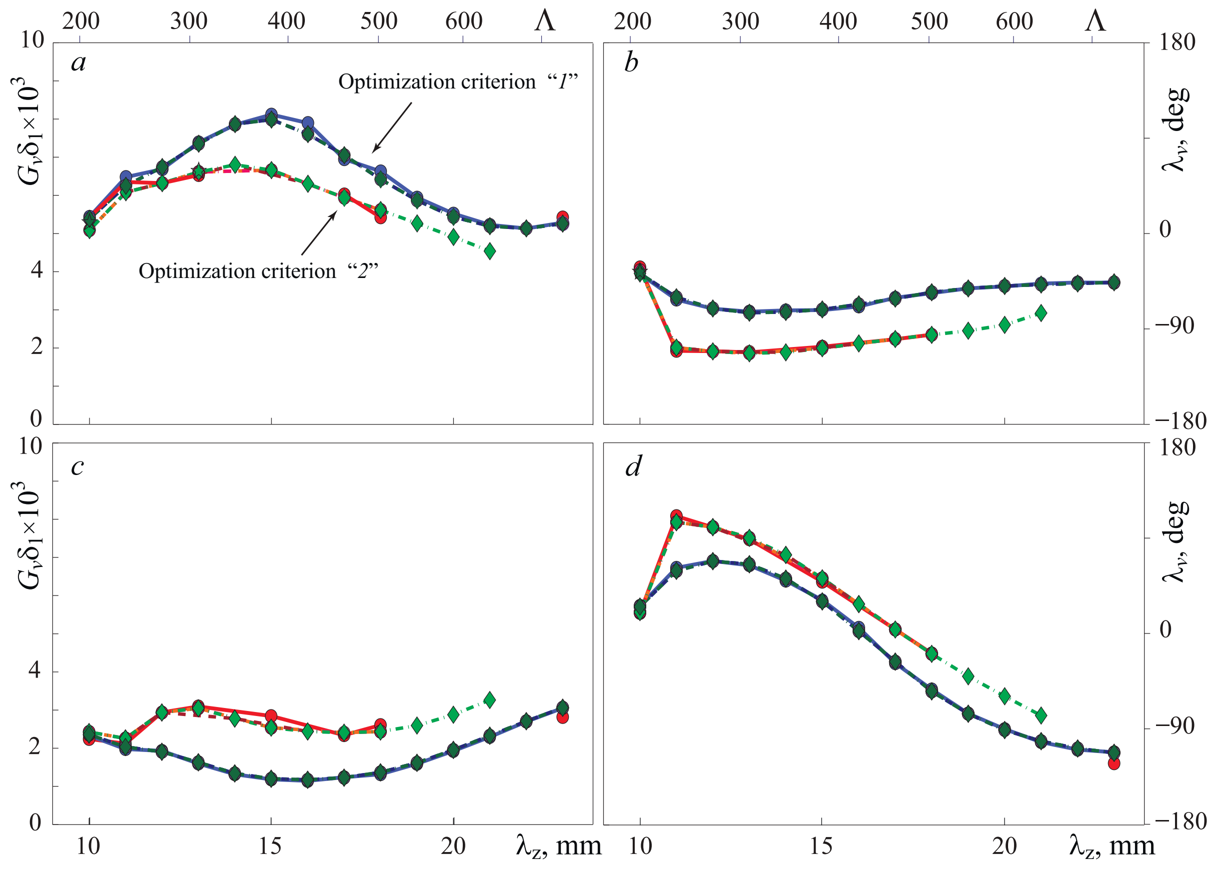

Figure 1. Amplitudes (*a*,*c*) and phases (*b*,*d*) of distributed receptivity coefficients versus spanwise wavelength of exciting Görtler vortices: *a*,*b* – x = 312 mm (G^* = 8,2), *c*,*d* – x = 900 mm (G^* = 18,7). f = 15 Hz (dimensionless frequency parameter F = 17.04). Different symbols denotes values obtained by using different fitting algorithms and criteria

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References

[1] Boiko A.V., Ivanov A.V., Kachanov Y.S., Mischenko D.A., Steady and unsteady Görtler boundary-layer instability on concave wall. *Eur. J. Mech., B/Fluids*. 29, **1**: 43-66, 2010.

[2] Borodulin V.I., Ivanov A.V., Kachanov Y.S., Komarova V.Y., Distributed two-dimensional boundary-layer receptivity to non-stationary vortical disturbances in the presence of surface roughness. *Thermophysics and Aeromechanics* **13, 2**: 183-208, 2006