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Effects of Blowing on the Görtler Instability of Boundary Layers

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Introduction

It is known that Görtler instability may considerably accelerate the laminar-turbulent transition process in boundary layers over concave walls. Therefore, it is of interest to investigate different methods of manipulation of such flows with a view toward eliminating or at least reducing the intensity of this instability. The present analysis deals with the effects of self-similar blowing. It is an extension of an earlier work of Floryan and Saric[1] that dealt only with suction. Self-similar blowing has been considered by Kobayashi[2]; however, the present work is based on a model rationally incorporating the effects of boundary-layer growth[3] and, therefore, the present results represent a considerable improvement over the results of Ref. 2.

Theory

The linear stability of an incompressible two-dimensional boundary layer is considered. The leading-order approximation for the disturbance equations has the form[3]

$$\beta u + \frac{dv}{d\psi} + \alpha w = 0 \tag{1}$$

$$\beta U u + u\frac{\partial U}{\partial \Phi_l} + \frac{\partial U}{\partial \psi} v + V\frac{du}{d\psi} = \frac{d^2u}{d\psi^2} - \alpha^2 u \tag{2}$$

$$\beta U v + \frac{\partial V}{\partial \Phi_l} u + \frac{\partial V}{\partial \psi} v + V\frac{dv}{d\psi} + 2G^2 U u$$
$$= -\frac{dp}{d\psi} + \frac{d^2v}{d\psi^2} - \alpha^2 v \tag{3}$$

$$\beta U w + V\frac{dw}{d\psi} = \alpha p + \frac{d^2w}{d\psi^2} - \alpha^2 w \tag{4}$$

where u, v, and w are the disturbance velocity components in the streamwise Φ, normal-to-the-wall ψ, and spanwise z directions, respectively; p the pressure disturbance; U and V the streamwise and normal-to-the-wall basic-state velocity components; α the spanwise wavenumber; β the spatial growth rate in the streamwise direction; and $\Phi_l = \epsilon\Phi$, where $\epsilon = \nu/U_\infty\delta_r \ll 1$. The boundary-layer thickness δ_r is defined as $\delta_r = (\nu\tilde{\Phi}/U_\infty)^{1/2}$, where U_∞ is the freestream velocity, ν the kinematic viscosity, and $\tilde{\Phi}$ the distance from the leading edge.

The Görtler number $G = U_\infty\delta_r/\nu(\delta_r/\Re)^{1/2}$ is the critical stability parameter. Here $\Re$ denotes the radius of curvature of the wall. Equations (1-4), supplemented by the standard no-slip and no-penetration boundary conditions at the wall and conditions describing the decay of disturbances away from the wall,[1] form an eigenvalue problem for (α,β,G). For the case with blowing, the disturbances would not necessarily vanish completely at the surface. However, the boundary conditions are approximately valid when the holes or blowing slots are fine enough.[1] The level of self-similar blowing is defined by the blowing parameter γ, which is defined in Ref. 1.

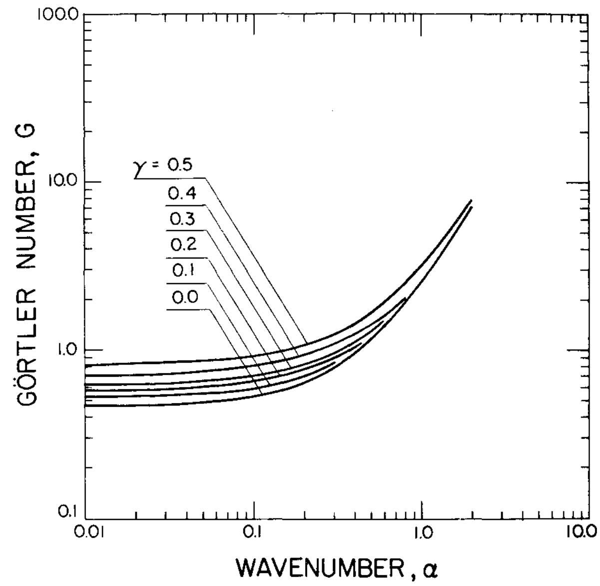

Fig. 1 Neutral stability curves for the Blasius boundary layer with self-similar blowing.

Results

Figure 1 displays neutral stability curves for different levels of self-similar blowing. The results suggest that blowing stabilizes the flow, which is in agreement with Kobayashi.[2] The critical Görtler number varied from $G_{\text{crit}} = 0.464$ for the no-blowing case to $G_{\text{crit}} = 0.833$ for blowing of $\gamma = 0.5$.

The disturbance growth process[4] is illustrated in Figs. 2-4. Figure 2 shows curves of constant amplification rate for blowing of $\gamma = 0.2$. These curves have an appearance similar to the no-blowing case,[3] except for the small-amplification curves that seem to be more compressed. Figure 3 displays the total amplification of the disturbances that occurred between the neutral curve and a chordwise location corresponding to the Görtler number $G = 20.0$. The total amplification is defined as[1]

$$A = \exp\left[\int_{G_0}^{G} \frac{4}{3}\frac{\beta}{G} dG\right] \tag{5}$$

where $A(G_0) = 1$. Here A denotes the amplitude of the disturbances and subscript 0 the initial conditions. Each integration begins at the neutral curve and follows the same vortex defined by the constant-dimensional wavelength λ downstream. The results, which are presented in terms of the wavelength parameter[1] $\Lambda = U_\infty\lambda/\nu(\lambda/\Re)^{1/2}$, suggest that,

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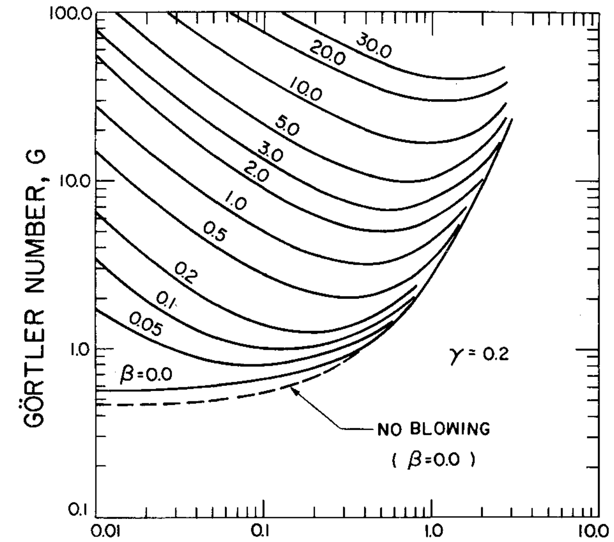

Fig. 2 Curves of constant amplification rate β as a function of Görtler number G and wavenumber α for the Blasius boundary layer with self-similar blowing of $\gamma = 0.2$.

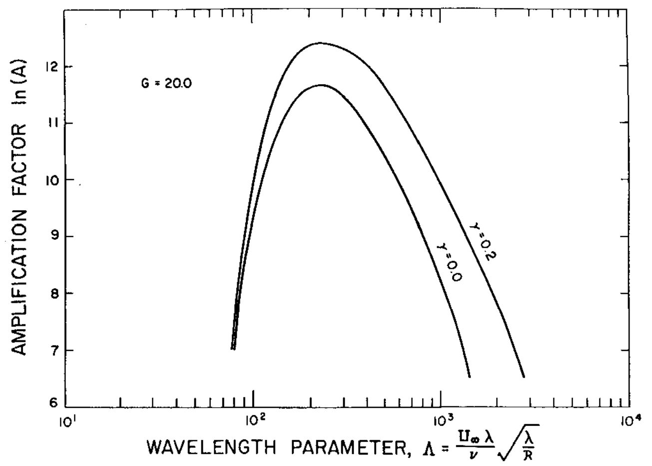

Fig. 3 Curves of total growth of disturbances as a function of the wavelength parameter Λ at the streamwise location corresponding to Görtler number $G = 20.0$. Calculations are for the Blasius boundary layers without blowing and with self-similar blowing of $\gamma = 0.2$.

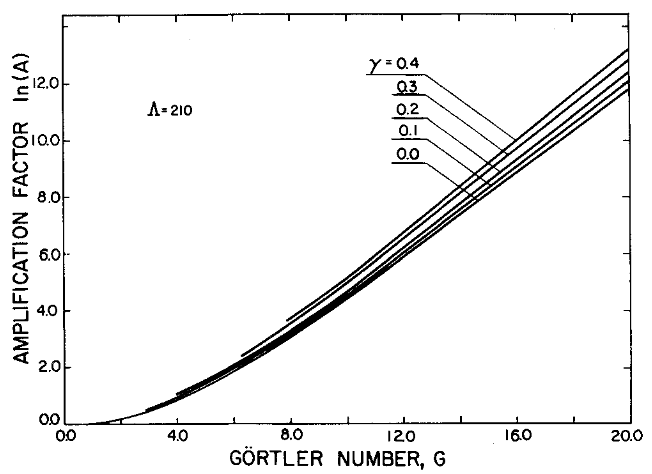

Fig. 4 Curves of total growth of disturbances as a function of Görtler number for the Blasius boundary layer with different levels of self-similar blowing. The value of the wavelength parameter Λ corresponds to the disturbances of the maximum total growth for the no-blowing case.

while it delays the onset of the instability, blowing increases the rate of growth of the disturbances and leads to a higher total amplification. The most amplified disturbances correspond to $\Lambda = 210$ for the no-blowing case[4] and blowing slightly increases this value. Figure 4 illustrates the variations of the total amplification of the disturbances for different levels of blowing as a function of Görtler number for vortices corresponding to $\Lambda = 210$. It may be concluded that while blowing increases the total growth, the growth process is qualitatively unaffected.

Conclusions

The effect of blowing on the Görtler instability of boundary layers has been studied for the case of self-similar blowing. An increase in blowing increases the critical Görtler number; however, it also accelerates the growth of the disturbances and thus may lead to an earlier transition.

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Statistical Processing of Multiplexed Data from Turbulent Flames

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Introduction

MULTICOMPONENT dynamic systems such as flames and turbulent flows are extremely complex. A full understanding of their behavior requires a knowledge of the time dependence of the interactions between the various components of the system. This in turn necessitates the accumulation of a vast store of time-resolved data. It also requires the simultaneous monitoring of two or more system components, which represents a severe experimental challenge. It is often impractical to record simultaneously the behavior of several data records without first multiplexing the data on the various system components. Multiplexing in component space makes a time-dependent analysis more difficult to execute. However, it is not as troublesome as many have supposed.

We know it is possible to obtain the real-time data record of a single spectral component of the data. This record can subsequently be analyzed to obtain statistical functions of the time evolution of a single measured parameter. It is also possible,

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