THE INFLUENCE OF STEADY BLOWING AND ROUGHNESS ON TRANSITIONAL SEPARATED BOUNDARY LAYERS

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Abstract This paper presents the results of a study between two types of forcing, namely steady blowing and a tripwire, on the control of laminar separated boundary layers. The analysis focuses on the differences in the transition process between these two types of forcing. This effect will be studied using direct numerical simulation. The main differences consists in the coherent structures formed during transition and the overall kinetic energy growth.

INTRODUCTION

Steady boundary layer forcing can be important in the size reduction of laminar separation bubbles or to trigger turbulence. In [1] and [2] it has already been shown that the downstream flow correlates with the particular upstream trip wire induced velocity perturbations. In [1] a study was made on the effect of different tripwires on the downstream evolution of the flow while in [2] the influence of typical numerical boundary conditions have been evaluated.

Steady forcing was used in [3] to study the influence of uniform or non-uniform tripwires. In that article immersed boundary conditions were used to model the tripwire, since it was hypothesized that this would lead to a different flow than in the case steady blowing would be used. Mainly because a tripwire introduces additional vorticity in the boundary layer due to the no-slip and impermeable boundary conditions. It was however never studied what the differences (if any) actually are and neither have they been made quantitative. With this contribution we would like to present a study in which we compare the two types of forcing, thereby contributing to closing the gap between the results in [1] and [2]. This study is therefore not only important for the particular case studied in [3] but also for other numerical or laboratory experiments in which a choice has to be made between using a tripwire or blowing.

We propose to do a parametric study in which we will compare the tripwire induced transition with the blowing induced transition. The simulations presented in this study have been performed using the DNS code which is described in [4]. This code was also used in [3] to simulate various boundary layers with a tripwire using embedded boundary conditions. The boundary layers are simulated in a numerical domain in which x, y, z are the streamwise, wall-normal and spanwise directions, respectively and u, v, w the corresponding velocities. To be able to do a parametric study, the domain size ($L_x \approx 1100\theta_0$, $L_y \approx 219\theta_0$, $L_z \approx 240\theta_0$) and the amount of grid points ($N_x \times N_y \times N_z = 513 \times 129 \times 192$), were reduced compared to the study in [3]. However, the inlet boundary condition $Re_{\theta_0} \approx 118$ was maintained while $V_\infty(x)$ was adjusted to take into account the lower domain height and still obtain a similar adverse pressure gradient as in [3]. The maximum blowing amplitude is $V_{bl}/U_\infty = 0.016$ and spanwise uniform (not discussed here) and spanwise fluctuating ($V_{bl}(z) \sim \sin(kz)$) blowing profiles were used. The height of the tripwire also varies as $h_r \sim \sin(kz)$ and has a maximum height of $h_r/\theta_0 \approx 0.6$.

RESULTS

Figure 1 shows the maximum perturbation energy k as a function of x and indicates that although the forcing wavenumber is the same, the growth rate is markedly different. This also results in a much shorter separation bubble in the case blowing is used, while also the separation point is moved downstream. The reason for this difference is apparently related to the strength of the perturbation and the extent to which the perturbation spreads in the wall-normal direction. Due to the low height of the tripwire, the perturbations generated by it are confined very close to the wall and as can be seen from figure 1 the perturbations viscously decay at first before starting to grow. On the contrary the perturbations introduced by the blowing forcing do not decay and steadily grow until transition to turbulence is completed.

Figure 2 shows contours of wall-normal velocity, v, in a plane parallel to the wall for steady blowing and roughness cases. The difference between the structures that develop during transition around $x/\theta_0 \sim 500$ can only be caused by a difference in the amplitude and the shape of the perturbations. Especially, in between the peaks of the tripwire the flow is being decelerated due to the no-slip boundary condition, causing the perturbations to become narrower in comparison to the blowing induced perturbations.

It is, furthermore, interesting to note that the structures develop around the same streamwise location in both cases, but the separation point is moved downstream only in the blowing case. This can be related to figure 1 which shows that steady blowing re-energizes the laminar boundary layer and hence delays flow separation. On the other hand the tripwire generates low-amplitude distortions in the laminar boundary layer that only trigger the transition process but do not re-energize the whole boundary layer.

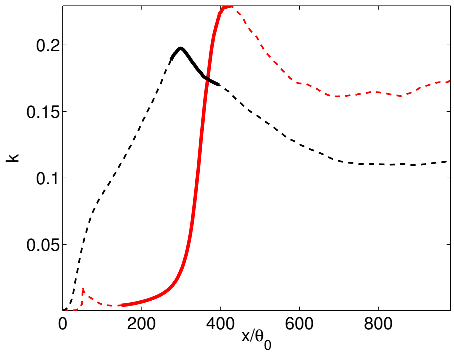

Figure 1. The maximum perturbation energy $k = \sqrt{1/3(u'^2 + v'^2 + w'^2)}/U_{0,\infty}$ as a function of x. Red line: k for tripwire, black line: k for blowing; ---- : attached flow, —— : separated flow.

The differences between the different wavenumbers is small in the sense that its choice does not seem to significantly alter the transition position. However, the transition process and the related structures do depend on the wavenumber.

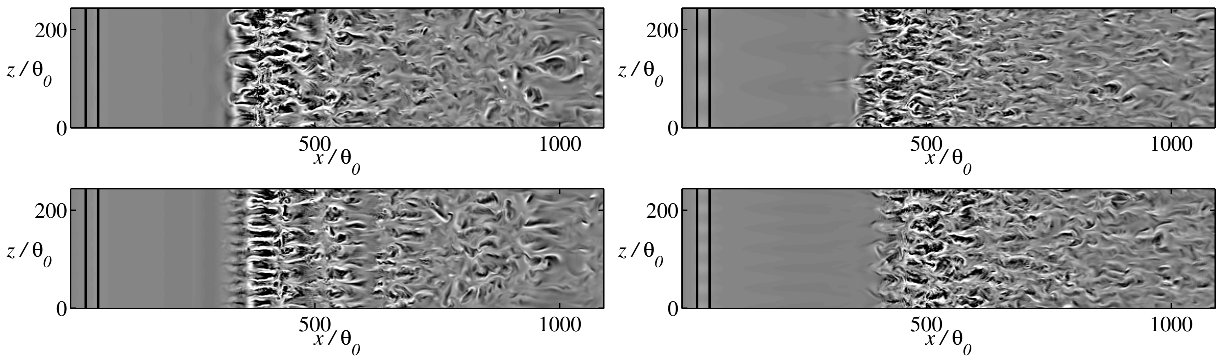

Figure 2. Instantaneous v/U_∞ at $y/\theta_0 = 3.1$. Left column: tripwire; right column, blowing. From top to bottom: 3d forcing spanwise wavenumber $k = 3$ and $k = 6$. The thick lines indicate the streamwise location of the forcing.

CONCLUSIONS

We have shown that substantial differences exist between using a tripwire or steady blowing when forcing a laminar separation bubble. More results will be obtained varying the blowing amplitude and spanwise wavenumber, and it will be probed if it is possibly to force the same transition with blowing as with using a tripwire. It is to be seen if simply increasing the height of the tripwire is sufficient to achieve this.

References

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