**The influence of tabs on fluid dynamic measurements downstream of a backward-facing step**

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**Abstract.** PIV-method was used to study the flow behind a backward-facing step in the presence of tabs for the Reynolds number $Re = 4000$. The studied tabs had rectangular shape and a height of 6 mm, and were installed with a step of 25 and 50 mm. The tabs, depending on the step, had a different effect on velocity profile. At the tab location, the profiles of the average longitudinal and transverse velocity were strongly deformed and became similar to the behaviour behind the solid rib. In the area between the tabs due to the adjacent pair of tab-induced vortices, the attachment of the mixing layer occurred earlier than at streamlining of a smooth step. The recirculation area was noticeably reduced for tabs with spacing of 50 mm, and at the same time, with a reduction in the distance between them to 25 mm, the size of this zone increased.

**1. Introduction**

Control over separated flows is an important fundamental and applied problem. Among numerous methods of controlling separation behind the step, passive methods should be noted as the most technologically simple. These methods are associated with the presence of additional objects within the flow: transverse ribs, generators, vortices, etc. The influence of two-dimensional obstacles on the flow dynamics is studied in [1-3]. Such barriers lead to a two-dimensional global restructuring of the flow. Vortex generators (tabs) create a smaller-scale global change due to their size, but the longitudinal vortices induced by them significantly affect the recirculation region behind the step [4]. The influence of height, location and spacing of rectangular tabs on heat transfer behind the step was studied in [5]. The authors of [5] found the most effective cases (in terms of heat exchange) for which our work studies the flow dynamics behind the step.

**2. Experimental setup and procedure**

The experiments were carried out in a 1 m long working channel with a rectangular cross section of $21 \times 150$ mm (see Fig. 1) made of transparent organic glass with a thickness of 8 mm. At a distance of 600 mm from the channel inlet there was the backward-facing step with a constant height $H = 9$ mm. At the step boundary there were tabs with square cross-section, a height $\Delta = 6$ mm, and a thickness $e = 3$ mm; the spacing between the tabs ranged from 25 to 50 mm. The Reynolds Number calculated by the height of the step $H$ and superficial velocity of 7 m/s, did not change and was equal to $Re_H = 4\ 000$. The average flow temperature was 20°C. At a distance of $25 H$ from the inlet the flow was stationary, and its velocity profile was close to the power one with the exponent $n \sim 1/7$. 

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The velocity fields were measured with the digital tracer visualization method (PIV). The equipment of the PIV-method included a pulsed laser with a double flash, synchronized with a digital camera for measuring the two-dimensional velocity field. The time interval between laser flashes in a pair of frames was 20 µs, and their duration was 5 ns. The complex was equipped with software to determine both averaged flow characteristics and statistical moments of the second and higher orders. For seeding the air flow with tracers we used SAFEX fog generator with Fog Fluid Standard working fluid. The average particle diameter of the tracers approximately equaled 1.0 µm. The measuring the area of the PIV complex had dimensions of 30 × 40 mm. For each region 4000 pairs of frames were obtained. The size of the camera matrices was 1360 × 1025 pixels, and in the calculation of velocity fields the image was divided into computational domains with dimensions of 32 × 32 pixels. The velocity fields were calculated using an iterative cross-correlation algorithm with 50% overlap of the computational domains. Then the velocity vectors were filtered in two ways: by signal to noise ratio and by median filter.

3. Result and discussion
The distribution of the mean longitudinal velocity at different distances from the step in the center of the channel symmetry is shown in Fig. 2. The scale of the longitudinal average velocity is shown in the upper right part of the figure, and $U_{ref}$ is the velocity on the axis of the undisturbed flow before separation. Similar to [6], the negative value of the longitudinal velocity component occurred at $X/H = 2÷5$ in the flow without perturbation. When introducing a perturbation, this value depended on the region of this perturbation input, in particular at $P = 50$ mm $X/H = 1÷3$, since there was no tab in the center of the channel symmetry at this step. At $P = 25$ mm the value of $X/H = 1÷5$ is influenced by the mounted tab. In work [6] it was noticed that the maximum recursive velocity behind a step does not exceed 0.2 $U_{ref}$, and for tabs with a step of 50mm this value does not exceed 0.1 $U_{ref}$, and at $P=25$ mm it exceeds the value of 0.3 $U_{ref}$.

For a smooth step in the absence of tabs, the area of the secondary vortex in the angular zone has a size of about one caliber. In the case of tabs, this area is not observed at all. When installing tabs with a step of 50 mm on the ledge boundary, the main vortex decreases and has a minimum size. In the case when $P = 25$ mm the size of the attachment area increases.

In the presence of tabs, at the first three calibers, the cross-velocity profiles differ markedly from similar distributions for a smooth ledge. At the level of the upper ledge boundary for a step $P = 50$ mm at a distance $X/H = 1$ a negative velocity develops, while for a smooth ledge it is close to zero. At $X/H = 2$ it reaches a minimum and then the negative transverse velocity begins to fall. By the 5th caliber, the transverse velocity equals the case of streamlining of a smooth step, while for $P = 25$ mm at the 8th caliber, the velocity profiles are still different.
Installing tabs with a step $P = 50$ mm leads to smoothening of the pulsation profile at initial stages and to faster attenuation in the subsequent ones (Fig. 4). Its maximum at the first caliber at the height of the ledge is less than at a smooth ledge streamlining. This is probably related to the interaction of pairs of longitudinal vortices caused by the tabs. The maximum peak value is also shifted downstream. In the case of $P = 25$ mm, the maximum pulsations are at the height of the tab. It seems that the dissipation of large-scale turbulent structures occurs with some delay compared to the cases of absence of tabs in the central region. All of them are characterized by an increase in the degree of turbulence near the attachment point.

The profiles of transverse velocity pulsations are qualitatively similar to the longitudinal velocity ripple, but they have lower values. For example, the maximum transverse velocity pulsations in
section $X/\frac{H}{\text{H}} = 1$ for a smooth ledge are $\sim$70\% less than the maximum of longitudinal component of velocity pulsations.

Figure 4. Profiles of RMS pulsations of longitudinal velocity.

Figure 5. Profiles of RMS pulsations of transverse velocity.

Directly behind the tab at $P = 25$ mm, the recirculation region is larger compared with smooth step streamlining and is $X_r/X_{00} = 1.057$. Its increase at $P = 25$ mm is much less than at a solid rib with a height of 3 mm, where the recirculation region increased 1.6 times [3]. For the case where there is no tab in the studied area, at $P = 50$ mm the recirculation region is reduced by almost half and $X_r/X_{00}=0.52$. The same phenomenon was observed in the work [4] when measuring the pressure distribution after the flow separation in the presence of tabs.
Summary
Using the PIV-method the flow over a backward-facing step in the presence of the tabs has been studied for the Reynolds number $Re = 4000$. The tabs used in the experiments had rectangular shape and a height of $6\text{ mm}$. The step between them was 25 and 50 mm. Depending on the spacing, the tabs had a different effect on the velocity profile. In the measurement area behind the tab, the profile of the mean longitudinal and transverse velocity is strongly deformed, its behavior becomes similar to that of the deformed profile behind a solid rib. In the measurement area between the tabs, due to the adjacent pair of tab-induced vortices, the mixing layer attachment occurs earlier than when the flow is separated behind a smooth step. The recirculation area drops noticeably in the case of tabs installed with a step of 50 mm, and for 25 mm the size of this zone increases slightly.

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