The Influence of Modulated Slotted Synthetic Jet on the Bypass of Hump

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Abstract: The articles deals with the influence of phase modulated synthetic jet on the aerodynamics of the hump in a closed test section of the Eiffel-type wind tunnel. Three experimental methods of observation, and techniques of measurement of this phenomenon, were used: the pressure profile using the Kiel total pressure probe, the velocity profile using the CTA probe and the visualization of the flow field using the hot film and the thermo camera. The experimental results with and without the influence of the synthetic jet was compared, as well the impact of the phase shift of the neighbouring synthetic jets. The flow around the hump without the influence of the synthetic jet was selected as a reference case. The results of the measurement are plotted and compared.

1 Introduction

The objective of the article is to verify and visualize the influence of the amplitude modulation and the phase shift of the synthetic jet on the flow field after the hump. The synthetic jet positively influences the vortexes which have marked effect on the magnitude and the character of the wake after the hump [1, 3]. The wake behind the hump affected by the synthetic jet with amplitude modulation has smaller pressure and velocity loses [2]. This effect needs to be analysed. The amplitude and the phase shift of the actuation of neighbouring synthetic jets generators are adjusted to discover the strongest positive effect on the wake size. The synthetic jet generator works on one of its resonant frequency. Pressure and velocity measurement techniques were used to verify the influence of the synthetic jet on the flow field behind the hump by flow field mapping. Thermal images of the surface of the hump with hot foil were acquired by thermo camera.

2 Methods and data

A model of the hump with dimensions 400 x 300 x 50 mm (L x W x H) was used (**Fig. 1**). The model was placed in an open-circuit wind tunnel with a closed test section, – dimension of the cross section area of which being 300 mm x 200 mm (L x W). Cells of the synthetic jet generator, installed inside the model of the hump, consist of two speakers placed in one chamber [4]. The cells are electrically engaged in two parallel branches. This enables to use the phase shift of actuating the neighbouring cells. The synthetic jet generator works on its resonant frequency in order to achieve the maximum of the synthetic jet intensity, i.e. output velocity, with minimum input power. Two methods were used to measure the flow field: the total pressure measured by the Kiel probe and the velocity profile measured by the CTA probe. The former was in the distance of 530 mm from the leading edge of the model, the latter 440 mm. Thermal images of hot foil, placed on the hump, were captured by thermo camera to visualise the influence of the synthetic jet.

3 Results of the experiment

Three basic experimental conditions were selected in this paper to show the positive influence the phase shift of the synthetic jet with amplitude modulation has on the flow field. The synthetic jet generator was deactivated for the reference condition. In the next two cases the synthetic jet generator actuated by carrying frequency f_c = 370 Hz and modulation frequency f_m = 60 Hz. In the one case, there was no phase shift. In the other, the phase shift of amplitude modulation was set in the opposite phase, by 180° (101010101). Dimensions of the area measured by the Kiel probe were 260.5 mm x 191.7 mm. Dimensions measured by the CTA probe were 251 mm x 140.4 mm. The starting points of these measurement areas were situated near the left bottom corner of the wind tunnel test section. Therefore, the wall effect of the synthetic jet is not visible on the right side of the wind tunnel.

3.1 The Kiel probe results

In **Fig. 2** we can see the total pressure fields in the position of 530 mm from the leading edge. In **Fig. 3**, the comparison of the total pressure distribution is shown, sections (A) being 0 mm, (B) 62.5 mm and (C) 125 mm. A positive influence of the synthetic jet on the wake size is visible in section B and C, with the phase shift (in C) in particular. The output slot of generator of the synthetic jet starts at about 6 mm from the side of the wall; then, the effect of the synthetic jet to the flow field by the side wall cannot be visible.

3.2 The CTA probe results

The velocity field measured by the CTA probe is showed in **Fig. 4** (position of 440 mm from the leading edge). **Fig. 5** shows the comparison of the velocity distribution in sections A, B, C. Compared to the total pressure distribution, the effect of the synthetic jet is the same. The visualisation of the flow field with the influence of the synthetic jet is showed in **Fig. 6**. The size of the red (hot) area indicates a positive effect of the synthetic jet. The smaller red area corresponds to the smaller size of the recirculation area.

4 Discussion

All methods clearly show a positive influence of the synthetic jet on the flow field around the model. Thanks to the effect of the synthetic jet the reduction of the wake size is shown in **Fig. 2** and **4**. At the bottom of the figure the boundary of the wake is corrugated. This is caused by the influence of the synthetic jet and by wall effect on the left side of the wall of the wind tunnel. The minimal wake for excitation with phase shift was discovered. In section A, X=0, the corner wall effect is considerable, the influence of the synthetic jet is suppressed. For the synthetic jet influence without any phase shift in section A, better results were obtained as far as the corner wall effect is concerned. This is due to the different wake size compared to the effect of the synthetic jet with a phase shift. The mean total pressure in the plane position of 530 mm (no actuation, no phase shift, phase shift) was p_{c1} = -7.22 ± 0.05 Pa, p_{c2} = -6.45 ± 0.05 Pa, p_{c3} = -6.50 ± 0.05 Pa. The mean velocity in the plane position (no actuation, no phase shift, phase) was c_1 = 6.43 ± 0.03 ms^{-1}, c_2 = 6.54 ± 0.03 ms^{-1}, c_3 = 6.63 ± 0.03 ms^{-1}.These values clearly show the contribution of the opposite phase shift to the decrease of the wake size. The visualization by the thermal camera again shows the advantage of the synthetic. The thermogram is not able to show the cardinal contribution clearly in the case of no phase shift compared to the phase shift of the synthetic jet generator.

5 Conclusion

The synthetic jet generator placed on the top of the model of hump definitely has a positive effect to the wake size. This influence was verified by tree different measurement techniques. The opposite phase shift of the neighbouring synthetic jet cells in synthetic jet generator has a positive effect on reducing of the wake behind the model.

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Literature

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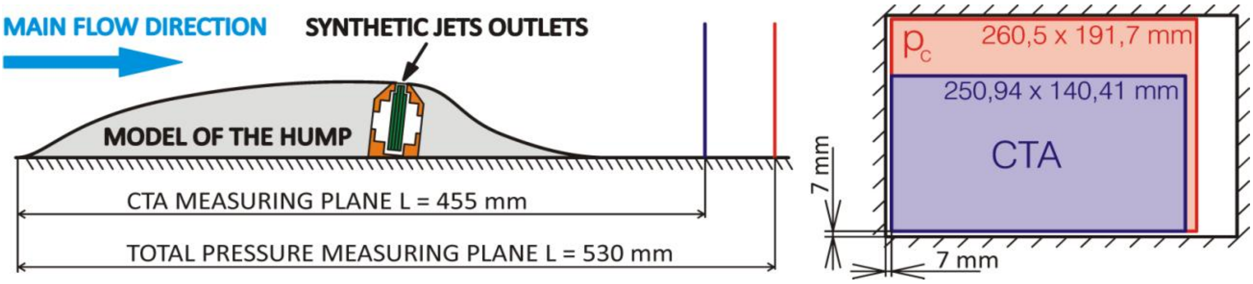

Fig.1 Model of the hump with synthetic jet (fore-and-aft section), assumed from [1]

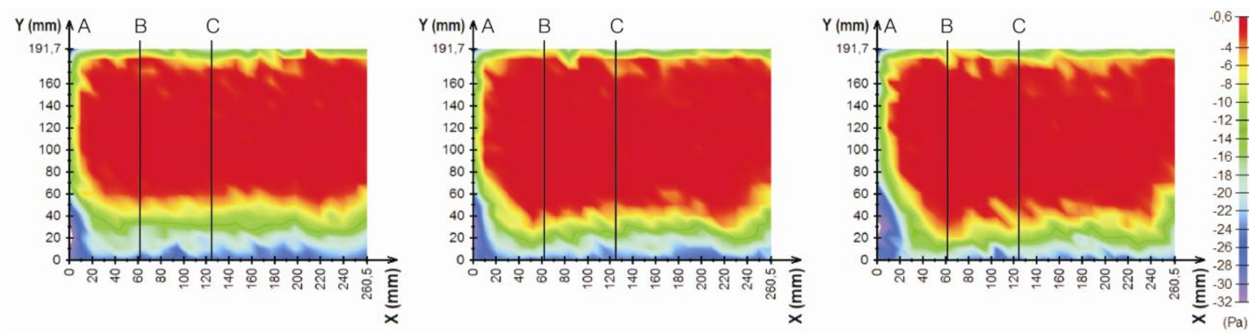

Fig.2 Total pressure field, view in the direction of the flow. From left: reference conditions - no actuation, no phase shift of the synthetic jet, and phase shift of amplitude modulation of the synthetic jet.

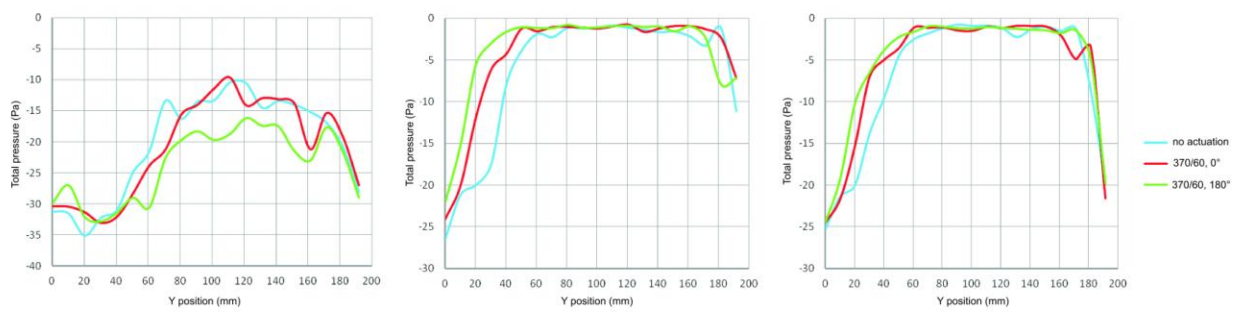

Fig. 3 Comparison of the total pressure distribution in sections. From left: X = 0mm (A), X = 62.5 mm (B), X=125 mm (C)

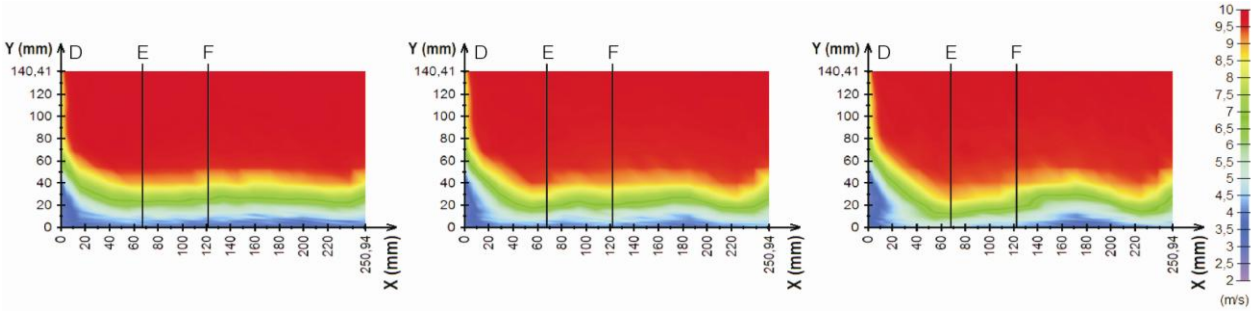

Fig.4 Velocity field, view in the direction of the flow. From left: reference conditions - no actuation, no phase shift of the synthetic jet, and phase shift of amplitude modulation of the synthetic jet.

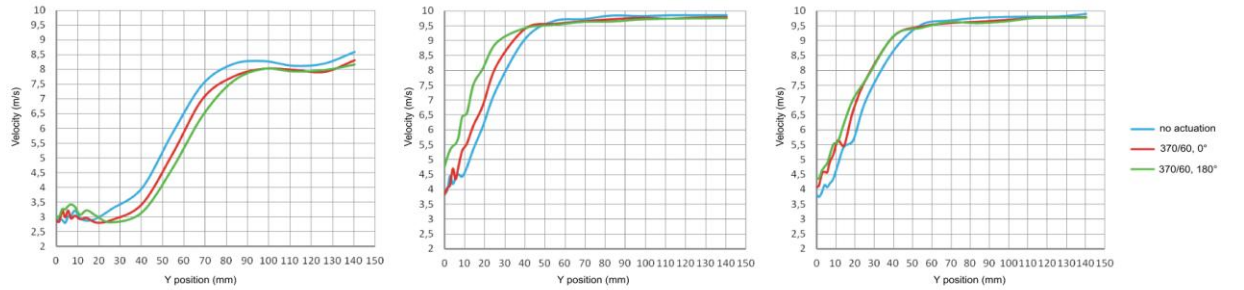

Fig. 5 Comparison of the velocity distributions in sections A, B, C

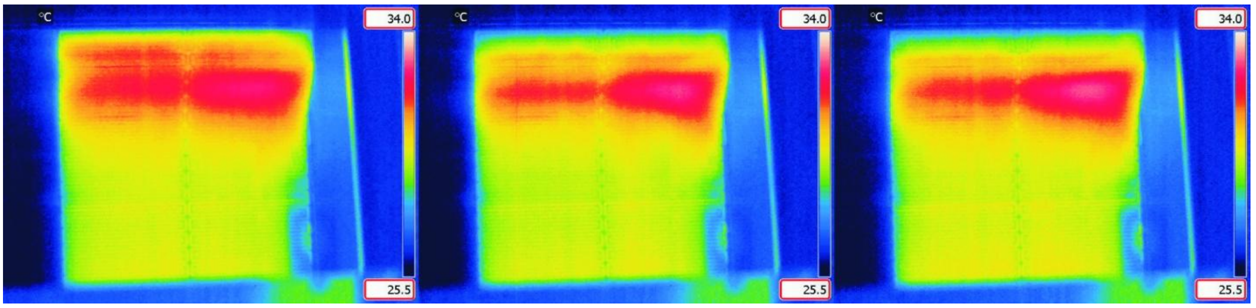

Fig. 6 Temperature field on the surface of the hump. From left: no actuation, no phase shift of the synthetic jet, and phase shift of amplitude modulation of the synthetic jet.