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ACTIVE CONTROL OF TURBULENT SEPARATION WITH AIR JET VORTEX GEENERATORS

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Abstract

In this work we present the results of experimental study of control the turbulent separation by air jet vortex generators. In spectrum of known methods of delaying of a turbulent separation the jet vortex generator was chosen. Advantage of this generator is ability of control of the kinetic energy injected to boundary layer. Additionally this method allow to control the flow separation by generating the counter rotating vortex's. Unique shape of air jet vortex generator was performed and results of testing are presented.

Key words: Flow control, Turbulent separation, Air jet vortex generators, Pressure gradient

INTRODUCTION

The delaying of boundary layer separation is important in aspect of hight lift generation and drug reduction. Among of many passive mechanical turbulizator's we notice this shapes with produce counter rotating vortex. One of this techniques was proposed (e.g.: Szumowski and Wojciechowski, 2005) where two semi circular rods was set up in V-shape to produce stream-wise vortices's in turbulent boundary layer. Another is presented (e.g.: Godard and Stanislas, 2006) whose study thin plates vortex generators to generate co-rotating and counter-rotating vortices's.

Another group of devices for decreasing of separation are jet turbulizator's. This devices cane be performed as line of a holes with increase energy in turbulent boundary layer, or more sophisticated combinations with generates stream-wise vortices's like this described also by Godard and Stanislas. In extensive paper they are presenting efficiency of methods for generating stream-wise vortex and surface stress in separation region. First part of that work show that sequence of counter-rotating vortex's is two time more effective than co-rotating vortex's. In second part they test gap-jet vortex generators and optimal results was obtained for 15° angle between gap and undisturbed flow vector. In presented paper most interest was focused on a static pressure measurements due to analysis of the distribution of parameter along tested surface.

EXPERIMENTAL SETUP

The goal of experiment was finding of jet intercity influence on position of flow separation. Special experimental setup was presented in figure 1. The main part of hardware is a case with elements whose made continues slot in "V" shape (top view on fig.1.). Angle of

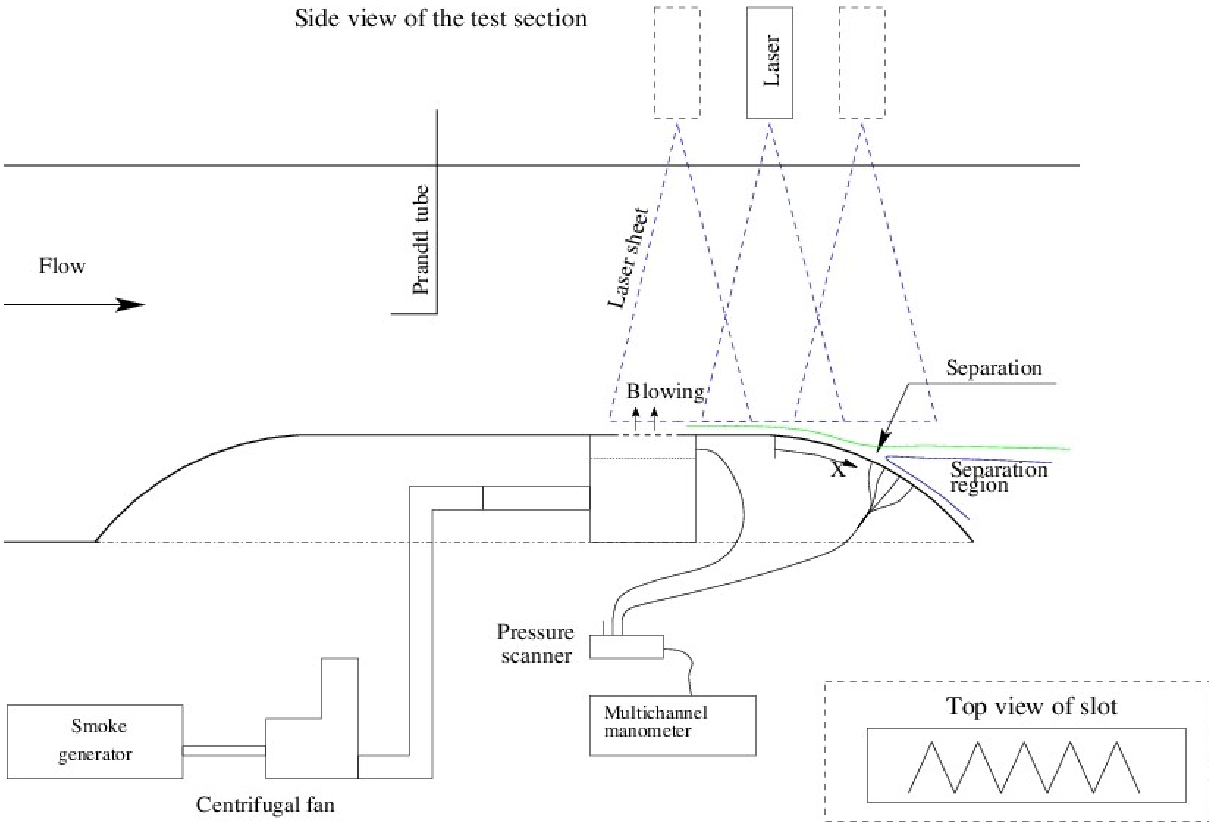

Fig. 1: Experimental setup

slot was 15° in reference to free stream vector and width 1mm. Separation was tested on curved shape witch radius R=500mm. Experiment was carried out in wind channel, typical velocity of flow was 10-20m/s with turbulence level 0,5% in free stream. Velocity and

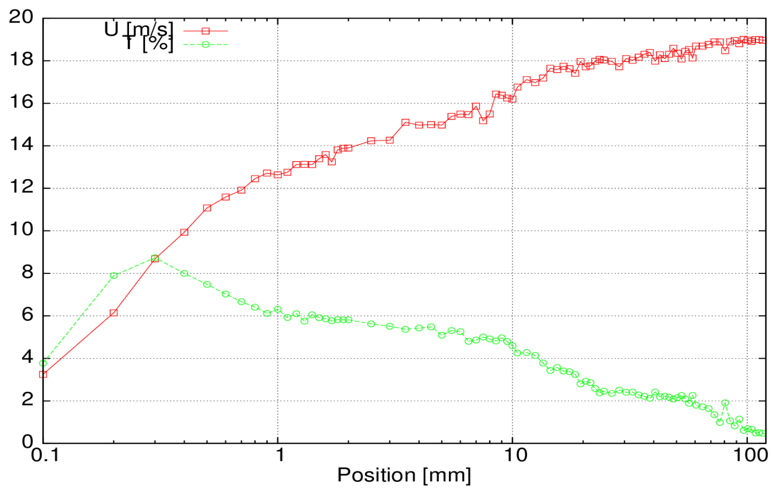

Fig. 2: Velocity and turbulence level distribution in boundary layer.

turbulence profile were measured with Hot-Wire Dantec bridge and straight single probe. Signal was acquired with 16bit National Instrument module. Data from 1second was acquired with 100kHz sampling and 10kHz low pas filter, for RMS signal also 10Hz high pas filter was used. The measurements of pressure field was performed with Pressure System acquisition system controlled by home made software with LabView. Pressure distribution was taken in curved surface respectively to geometrical coordinate marketed in figure 1. additionally total pressure and pressure inside of the case was measured, all in reference to static pressure on the Prandtl tube. Intensity of actuator was compared to ratio of pressure inside of case to dynamic pressure ($p_{case}/p_{dynamic}$). For presenting quality results smoke and oil visualizations were prepared. Smoke were illuminated with 1W, 523nm, DPSS laser from top in center plane of test section. In this view two dimensional separation was observed. Oil visualizations was prepared on curved area close to separation region and in vicinity of the jet slot.

The surface where separation is tested precedent are smooth, and slots are made from 4mm plexiglas, and precision of edge adjustment is 0,3mm.

RESULTS AND DISCUTIONS

Pressure distributions

Pressure distributions profile over near separation region shows precisely results of direct actions of the actuators. On the figure 3 typical pressure distributions are presented. On the plot cane be noted that after separation the pressure profile is constant.

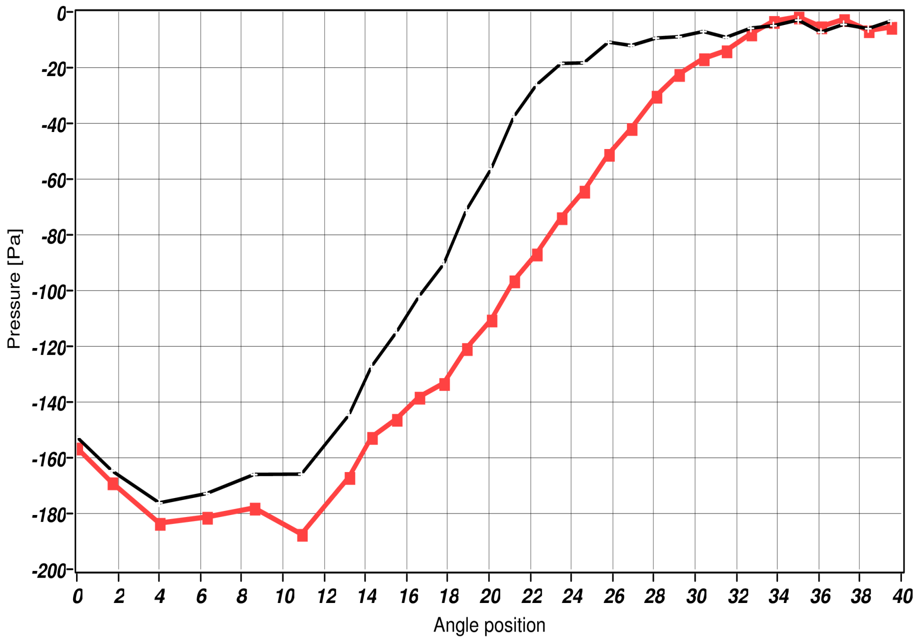

Fig. 3: Typical pressure distribution along curved shape in function of angle (deg), black line correspond profile without jet, and red line represent profile with jet.

For quantitative characterization of benefits of using vortex generator the coefficient of retrieve of pressure was defined:

$$C_p = \frac{1}{p_d} \int (p_0(x) - p_i(x)) dx \quad (1)$$

where: p_d – dynamic pressure, p_0 – pressure distribution without vortex generator, and p_i – pressure distribution with vortex generator.

For that defined coefficient were made tests for different free stream velocity. Results are presented in figure 4 in function of intensify of actuator. For low intensity factor ($p_{case}/p_{dynamic}$)

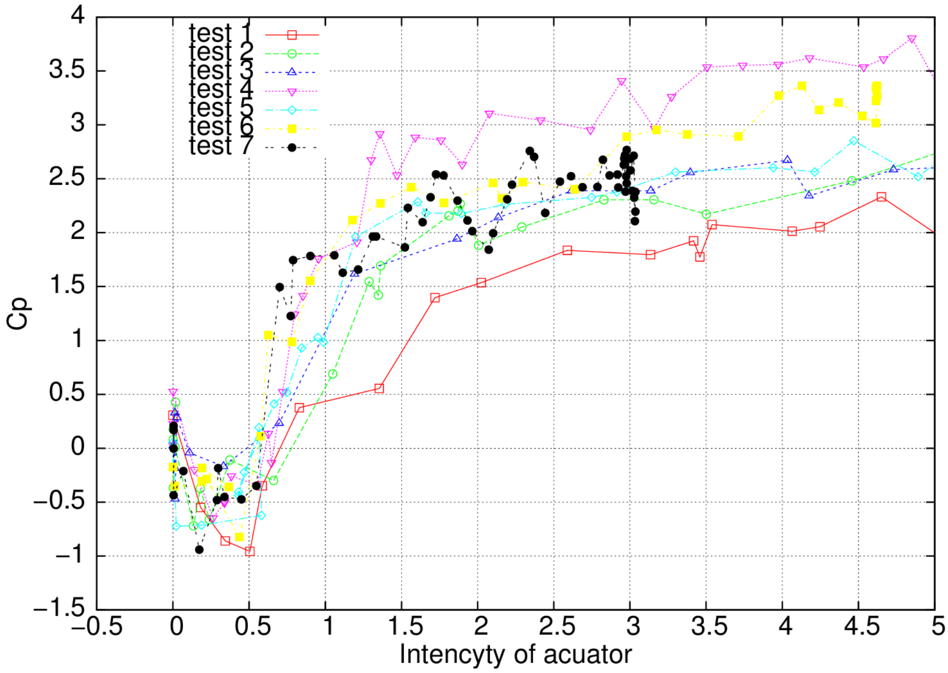

Fig. 4: Diagram of relationship of pressure coefficient Cp in function of jet intensity factor.

coefficient Cp is low and even negative that prove about acceleration of separation. Above value 0.5 significant grooving is noted, and above 1,5 saturation of Cp occurs.

Flow visualizations

Another step of research was preparing of visualizations for affirmation of process. Oil visualizations close to slots (fig. 5a) prove existing of longitudinal vortex structure with reacts

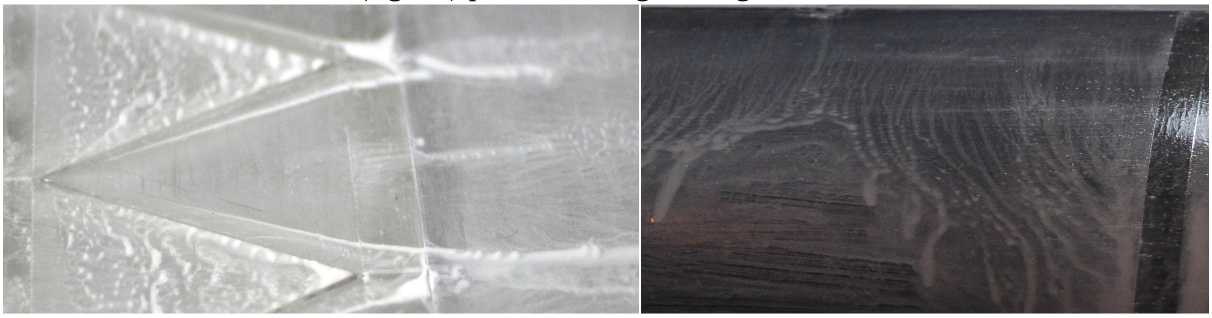

Fig. 5: Oil visualizations: a) in vicinity of slots – top view, flow from left to right, b) on curved shape – rear view, flow direction up to observator.

characteristic line along the slot. Small inclination between slot and line inform about expansion of longitudinal vortex. Detailed understanding of flow behavior in this region require using of Particle Image Velocity.

In figure 5b oil visualizations for curved shape are presented. Area with flow non-separated and regions with important lower velocity cane be noted. Visualization is showing that the actuator is delaying separation but in narrow zone close to center of channel. On the picture is visible center plane where a scotch is covering pressure holes to avoid penetration of it by oil.

In figure 6 the smoke visualizations in symmetry plane are presented. The smoke were injected from air jet vortex generator, and is traveling with boundary layer. In moment of

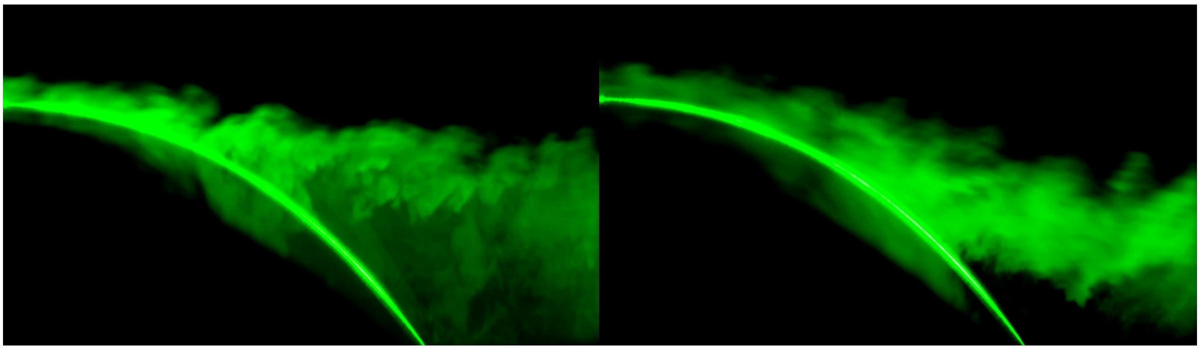

Fig. 6: Smoke visualizations in 2D side-view: a- without jet, b -with jet. Flow from left to right.

separation dye recede from surface. Curved surface is made from black plexiglas and in pictures are visible small reflections of smoke. Smoke visualization consistently confirm results from pressure distributions.

CONCLUSIONS

During experiments the pressure distributions, oil and smoke visualizations on curved surface were performed. The optimization of jet flow rate vs stream velocity was done witch pressure coefficient containing pressure profiles on curved shape. Our active vortex generator is made by continuous slot witch characteristic shape. The investigation show that this provide similar effect as passive vortex generators proposed by Szumowski and Wojciechowski. The conditions of experiments in both cases where similar. Optimal range of pressure ratios in active vortex generator was presented. Visualizations confirm influence of jet with decrease separation region showing at once complexity of flow structure.

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