

EXPERIMENTAL STUDY OF SYNTHETIC JETS FOR THE CONTROL OF FLOWS SEPARATION IN THE ENGINE'S DUCTS

V.A. Stepanov*, A.Yu. Makarov*, V.P. Maslov*
* CIAM. P.I. Baranova

Keywords: *synthetic jets, PIV experiment*

Abstract

In this paper we conducted research aimed at finding ways to reduce the current losses in the gas-dynamic curved diffusers aircraft engines and reducing their length. We consider the effective means of influence on the flow separation zone in the channels in order to reduce zones size or eliminate them.

1 Introduction

In this paper there have been studies in searching of modern ways to reduce length and pressure losses in diffusers of aircraft engines. Active means of influence on the flow separation zone in the channels in order to reduce or eliminate them have been considered. Active control methods include pulsing blowing and sucking air from the boundary layer, as well as synthetic jet. In this paper research of using synthetic jets in a diffuser are carried out. The work of generator of synthetic jets (GSJ) consists of alternating phases of injection and suction of air with zero average air flow. One advantage of using synthetic jets is that the additional air flow to create them is not necessary. Only the energy required to excite oscillations in GSJ cavity. Previously flow in the diffuser with flow separation zone has been studied in detail [1-3]. The calculations and experiments demonstrated the possibility of flow control using synthetic jets [4-9]. In this article development of synthetic jets control method continued and new experimental data are presented.

2 Experimental study of flow

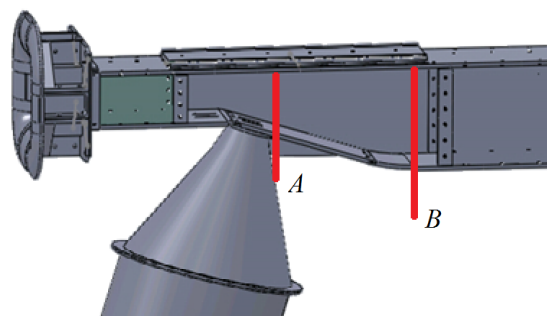


Fig. 1. General view of the channel with a generator of synthetic jets

For detailed experimental studies of the structure of synthetic jets the diffuser channel with two large size synthetic jets was made. Area ratio of the diffuser exit and entry is $F_{out}/F_{in}=2$. Diffuser wall inclined at an angle $\alpha = 15^\circ$. The bottom wall of the channel set of generator of synthetic jets (GSJ) comprising a closed chamber with two rectangular longitudinal slits and a resonator. Channel width is 100mm, entrance height is 75mm, exit height is 150mm. Jet generated two slits 40x4mm and the distance between the slits is 23mm. There are two places for a GSJ in the channel: before and at the beginning of the diffuser section. General view of the channel presented in Figure 1. Channel is equipped with optical windows for research instantaneous flow structure using the PIV (Particle Image Velocimetry). Measurement of velocity fields was carried out in two sections, as shown in Figure 1. Maximum electric power generator of synthetic jets was 115W; frequency was ranged from 50 to 300 Hz. Flow parameters were measured using Pitot tubes and using the PIV method, which is currently the most promising method

for measuring the gas flow rate. This method allows measuring the instantaneous field of two or three components of velocity in a noncontact manner, a wide range of flow rates.

Synchronization between registration instantaneous velocity field by PIV and generator device was used. For excitation of the generator a sinusoidal waveform was chosen. For synchronization averaged velocity field with a phase shift ranging from 0° to 360° through 30° was used. Registration of velocity fields and velocity fluctuations were carried out in two sections: 30 mm (section A in Figure 1) and 120 mm (section B in Figure 1) after expiration of synthetic jets slits.

The developed GSJ could reach speeds of jet output up to 40m/s at a supply voltage 30V. The PIV measurements of velocity field of the radiation in resting space are presented in Figure 2. It was found that air flow at a distance of 10-15 calibers become unidirectional.

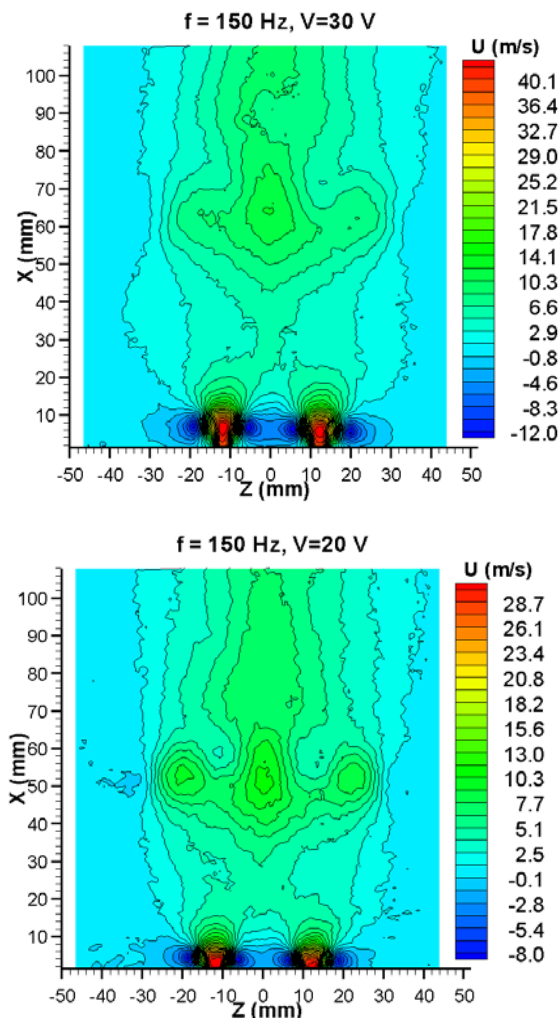


Fig. 2. Fields wall-normal velocity component.

Two places to install a generator of synthetic jets were provided in the channel - immediately before and in the beginning of the diffuser section. The second variant provided greater positive effect to stream, so all the data in the article refer to it.

Fig. 3 shows the velocity field in the cross section A at Mach number in diffuser inlet $M_{inlet}=0.1-0.5$ modes without jets and with GSJ. Resulted velocity field was averaged over several measurements of instantaneous velocity field. Since that the glares are difficult to remove during registration fields by PIV, you can see some pictures of education, marked by rectangles, which should not be taken into account in the analysis of the velocity field.

It may be noted that the penetration of the jets in the core flow decreases with increasing Mach number at the input. When the Mach number changes from 0.1 to 0.5 jets exposure depth varies in the range 25mm - 5mm, respectively. From these graphs it is seen that the longitudinal velocity in zone near the generators synthetic jets decreases and the fields of transverse velocity has areas with alternating directions of the vertical velocity. Change in the direction of the vertical velocity is due to the formation near the slits of GSJ pair counter-rotating vortices. These vortices intensify the transfer of energy from the core of flow to the wall delaying the appearance of flow separation.

In the figure 4 shown the time sequence of averaged longitudinal velocity U fields with GSJ. Phase changes from 0° to 330° with step 30° . Amplitude of power supply of GSJ is 30V and frequency is 150 Hz. Mach number at the entrance is 0.1. In the figures 4.a-4.e phases of boundary layer suction is shown, it is seen that the region with high speed pressure practically adjacent to the channel wall. In the figures 4.f-4.j jet blowing is shown. Mushroom-type structures of vortex pairs are clearly seen.

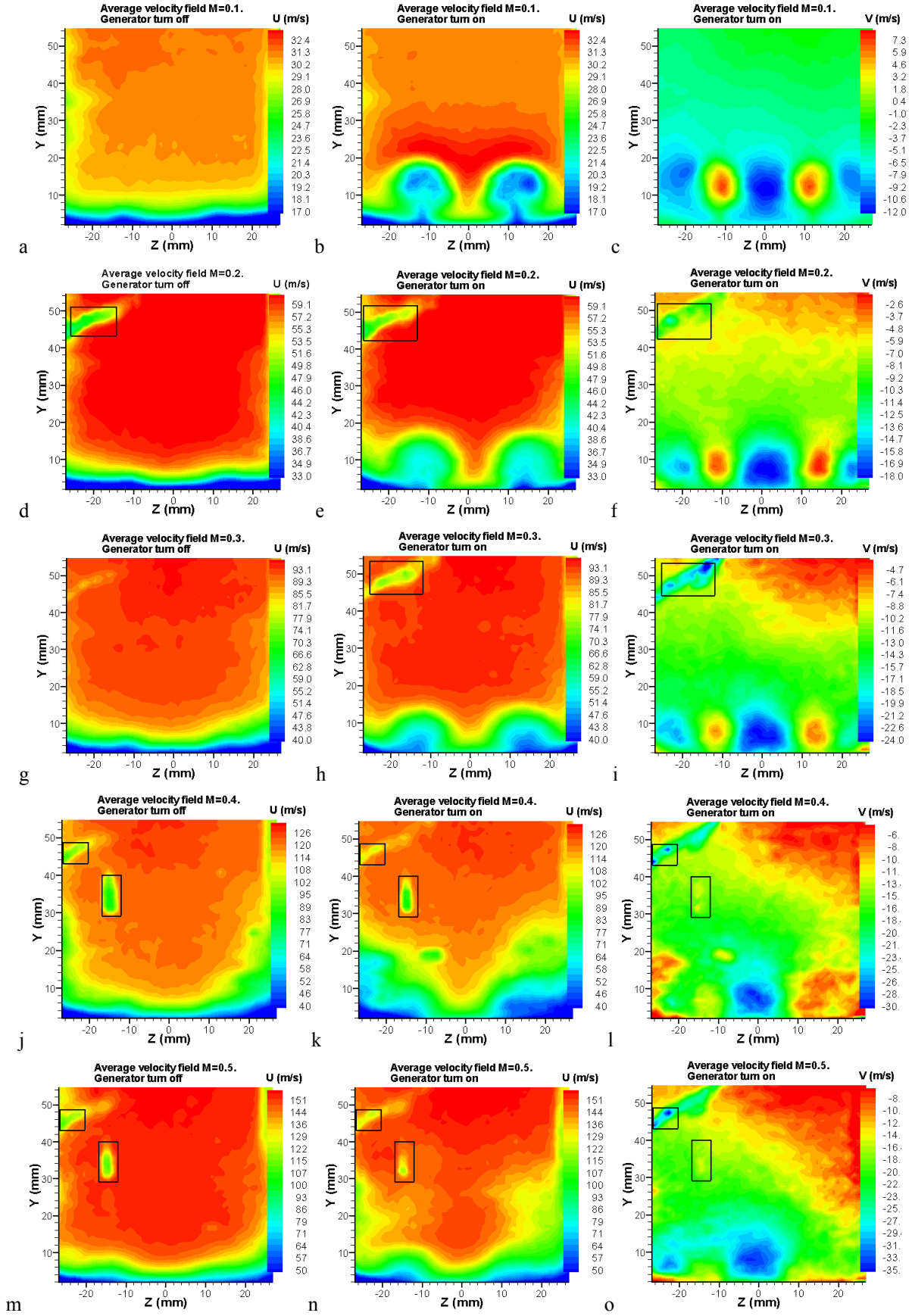


Fig. 3. Fields average speeds. Longitudinal velocity U without GSJ (a, d, g, j, m), the longitudinal velocity U with GSJ (b, e, h, k, n), the vertical velocity V mode with GSJ (c, f, i, l, o) with power supply 30 V and a frequency $f = 150$ Hz for the Mach number at the entrance $M = 0.1 - 0.5$.

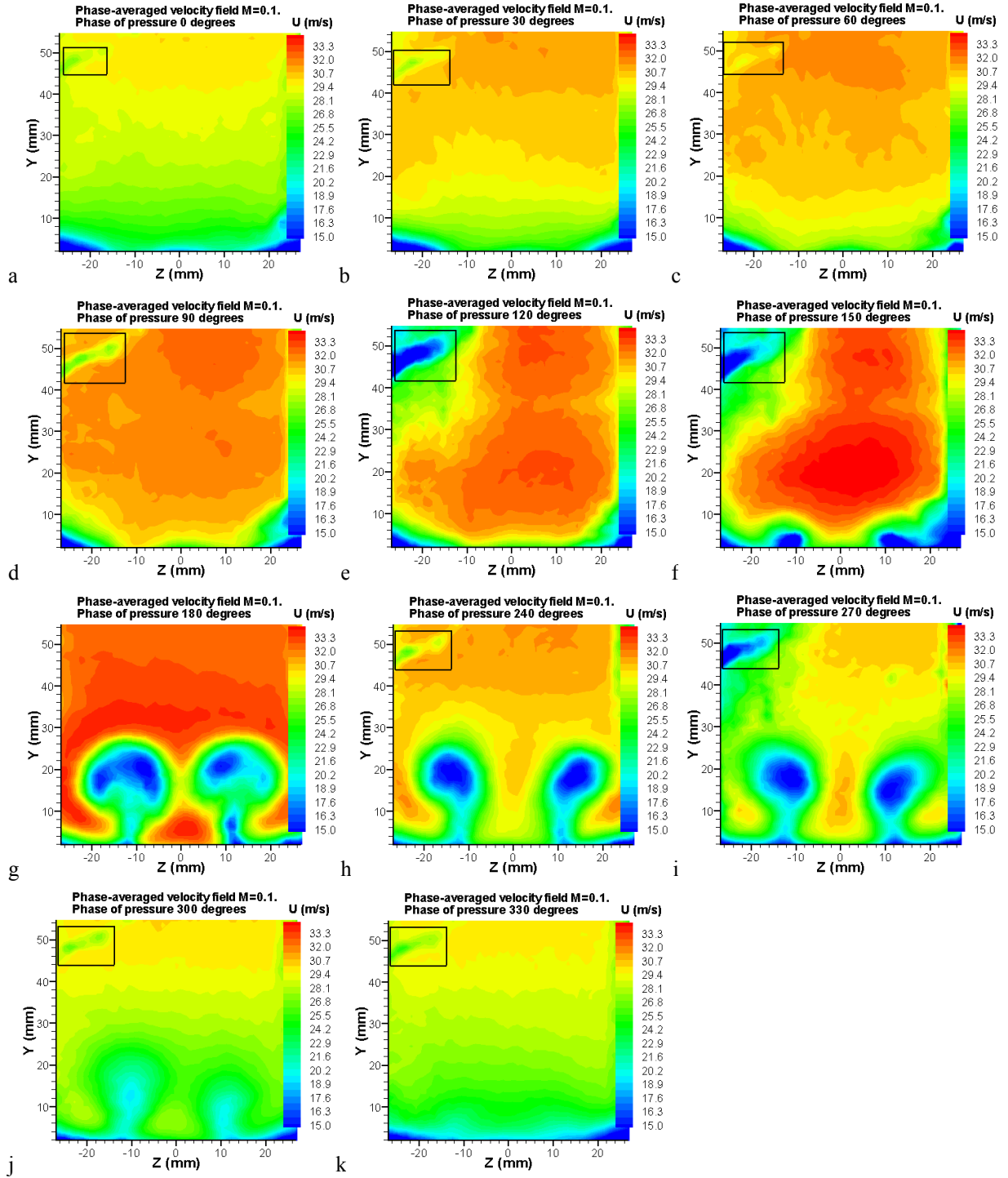


Fig. 4. Sequence slicing time fields to the median longitudinal velocity U mode with injection (phase change from 0° - and up to 330° - k) with the amplitude of the voltage on the dynamic head $U = 30$ V and frequency $f = 150$ Hz for the Mach number at the entrance $M = 0.1$.

EXPERIMENTAL STUDY OF UNSTEADY MECHANISMS OF ENERGY SUPPLY FOR THE CONTROL OF SECONDARY FLOWS IN THE ENGINES DUCTS

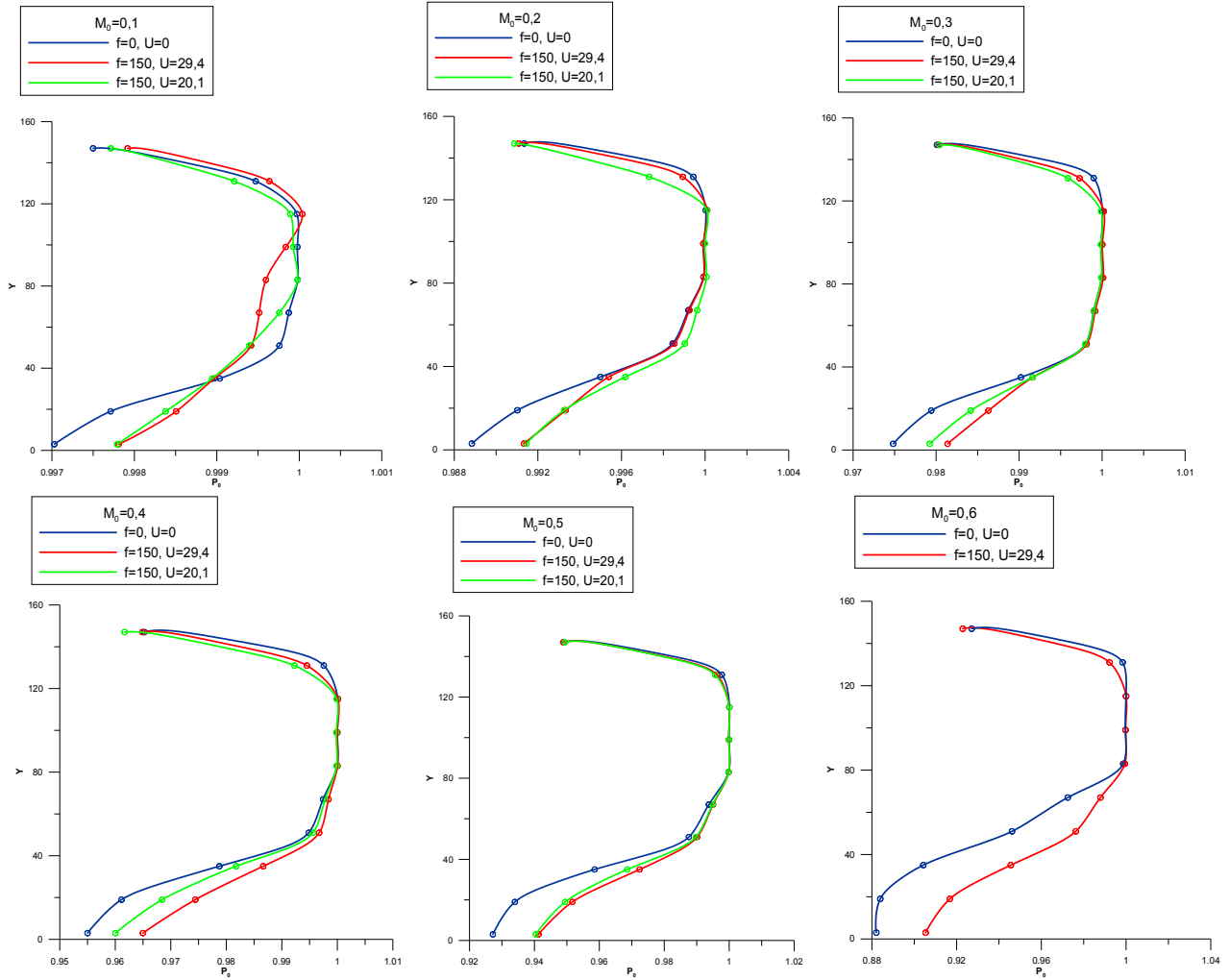


Fig. 5. Profiles of the total pressure in the B section in the channel center for a range of Mach numbers at the inlet 0.1 - 0.6.

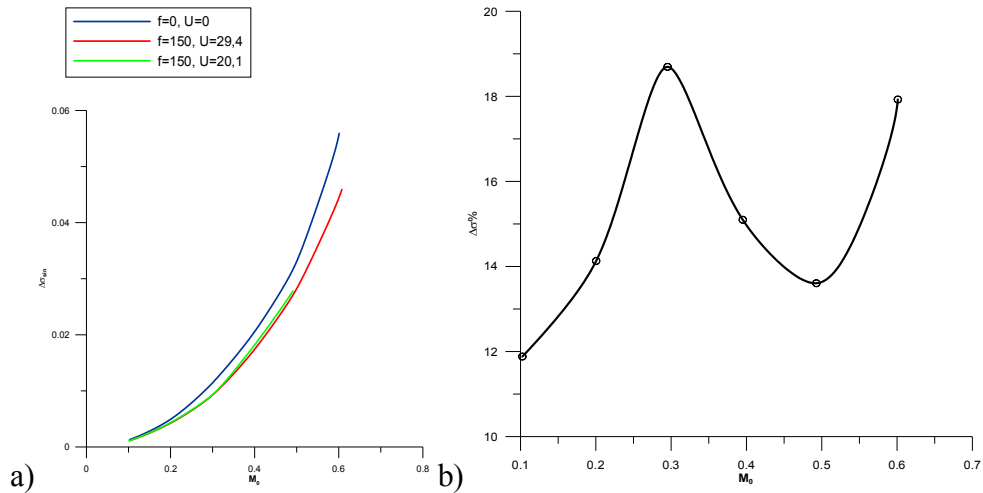


Fig. 6. a) The dependence of the total pressure losses in the diffuser outlet section (section B). The Mach number at the inlet without jets and with GSJ with frequency 150 Hz and the amplitude of the supplied voltage 20.1 and 29.4 V. b) The relative level of the total pressure losses.

Measurements of the velocity fields were made in section B. It was found that since the $M_{\text{inlet}}=0.2$ at the end of the diffuser section formed flow separated zone. From the analysis of the velocity fields for modes with and without GSJ it was found that for $M_{\text{inlet}}=0.2-0.5$ GSJ eliminates flow separation zone in the central part of the channel and makes the flow more uniform. PIV measurements allowed collect statistics for the velocity fluctuations calculation. It is observed that in section A velocity fluctuations level increases with GSJ three times. At the same time in section B the velocity fluctuations level falls to two times. This is due to the disappearance of the unstable flow separation zone.

Scanning of total pressure fields with movable Pitot pressure probe combs allowed quantifying the level of the total pressure losses in the channel. Fig. 5 shows the profiles of the total pressure in the channel center of section B. Three modes are showed: without GSJ and with GSJ working at a frequency 150Hz with two supply voltages 29.4V and 20.1V for the range of Mach numbers at the inlet 0.1-0.6. Increase in the total pressure near the bottom wall of the diffuser with injection of synthetic jets may be noted, indicating the weakening or disappearance of flow separation. At Mach number 0.1, we see that the more power GSJ is too high, and spoil flow. At Mach numbers 0.1-0.2 jets with lower energy were better than more powerful. At Mach number more than 0.3 more powerful jets have been most effective.

As a result, area averaged total pressure losses (in section B) were obtained depending on the Mach number at the inlet. modes without GSJ and with injection at the frequency 150 Hz and the amplitude of the supplied voltage 20.1 volts and 29.4 were carried out (Fig. 6. a). Figure 6. b shows the relative level of total pressure losses reduction when the Mach number at the inlet of the diffuser in the range 0.1-0.6.

3 Conclusions

Research has shown that in the range of Mach numbers at the channel inlet 0.1 - 0.2 there is total elimination of the separation zone and total pressure losses reduced by 12-18%. The optimal frequency of GSJ, which was the highest loss reduction was found and equals 150Hz. At Mach numbers 0.3 - 0.6, a significant decrease in the separation zone (zone of reverse currents were only in the corners of the channel), reduction of losses while was 14-20%.

Studied the effect of two powers synthetic jets: 50 and 115 W. It is shown that the relative efficiency of 50w power GSJ falls slightly (by 10-15%). Obtained that the gain from the use of GSJ exceed power of the GSJ. So the increase of total enthalpy of flow at the outlet when $M>0.3$ exceed power of GSJ several times. Was found that level of pressure fluctuations is greatly reduced at the channel output.

For a detailed study of the structure of synthetic jets and creating a database for numerical methods verification measurements of unsteady velocity field was made using the PIV. The fields of velocity and velocity fluctuations for the three modes (without blowing jets, with 50 W GSJ; with 115 W GSJ), seven flow rates $M=0.1-0.7$ and three frequencies 100, 150 and 200 Hz were carried out.

Study of non-stationary process of GSJ revealed some physical regularity of this unit, which makes it possible to apply the optimized version of the generator of synthetic jets on specific products of the aviation industry.

Work was supported by RFBR (grant number 12-08-00951-a).

References

- [1] Kashkin Y, Konovalov A, Krasheninnikov S, Lyubimov D, Pudovikov D and Stepanov V. *Experimental and numerical studies of the flow with flow separation in subsonic diffusers.*(In Russian) Fluid Mechanics, № 4, 2009.
- [2] Kashkin Y, Konovalov A, Krasheninnikov S, Lyubimov D, Panova O, Pudovikov D, Stepanov V, Torokhov V. *Study of 3D-flows in diffuser channels.*(In Russian) TVF. T. LXXXIII, № 1 (694). P. 65. 2009
- [3] Lyubimov D. *Investigation of the effect of the jets with zero mass flow rate on the flow in a curved diffuser.*(In Russian) TVT. T. 49. № 4. S. 557-567. 2011.
- [4] Kashkin Y, Lyubimov D, Makarov A, Pudovikov D, Torokhov S. *Numerical and experimental study of synthetic jets use for flow control in spatial channels. Proceedings of CIAM number 1341. Theoretical and Applied Gas Dynamics. V.1. Under. Ed. SY Krasheninnikov. M., Torus Press. 2010.*
- [5] Lyubimov, D., Potekhina I. *Numerical study of active control of the flow structure using synthetic jets on the characteristics and flow in a curved diffuser.* Materials XXIII Scientific and Technical Conference on aerodynamics. Volodarskogo. Pp. 159-160. 2012
- [6] Lyubimov D.A, Potekhina I.V. *Application of the high resolution large-eddy simulation method for the study of the influence of geometrical and gas-dynamic parameters of the synthetic jets on the curved diffuser flow.* abstracts part I. XVI International Conference on the Methods of Aerophysical Research. August 19-25.. Kazan. Russia. P. 180-181. 2012
- [7] Makarov A.Yu., Lyubimov D.A., Stepanov V.A., Pudovikov D.E., Krasheninnikov S.Yu., Toktaliev P.D., Torokhov S.A., Kaskin Yu.F. *Numerical and experimental modeling of active flow control methods for spatial diffusers ducts.* 4th European Conference for Aerospace Sciences (EUCASS). 2011
- [8] Lyubimov D., Makarov A., Potekhina I. *Experimental and numerical research of unsteady flow in curvilinear channel with active flow management using “synthetic” jets.* 28th International congress of the aeronautical science. September 23-28. Brisbane. Australia. Paper № 932. 2012
- [9] Lyubimov D.A., Potekhina I.V. *Investigation of Capabilities Synthetic Jets Application for Active Flow Control in Diffuser Ducts with Flow Separation Using High Resolution RANS/ILES – method.* EUCASS. Paper №80. 2013

4 Contact Author Email Address

mailto:keeper@ciam.ru

Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS 2014 proceedings or as individual off-prints from the proceedings.