INVESTIGATION OF CAPABILITIES SYNTHETIC JETS APPLICATION FOR ACTIVE FLOW CONTROL IN DIFFUSER DUCTS WITH FLOW SEPARATION USING HIGH RESOLUTION RANS/ILES – METHOD

D.A.Lyubimov, I.V.Potekhina
Central Insitute of Aviation Motors
111116, Moscow, Russia

Modern aircraft turbojet engines tend to compactness of some of their elements. In particular, this applies to the transitional diffuser channels between the stages of the turbine. Increasing the diffusers «aggressiveness», i.e. reduction the length while maintaining the area ratio inlet and outlet leads to a separation zone near diffuser walls and caused by their presence decrease performance of diffusers.

To reduce or eliminate the separation zones in the diffuser is the most effective active flow control, which is now being intensively developed. Promising is the use of devices with zero-net mass-flux of the working fluid. Resulting from the operation of such devices are usually called synthetic jet. In this case, the work of the active flow control is an alternating cycles of fluid expulsion from a closed cavity by changing its volume, followed then suction of the low-energy flow from diffuser. The cavity is joined only with inner part of the diffuser, so that the total in time mass-flux is zero.

A numerical study of the effect of the active flow control using synthetic jets on the separated flow in the S-shaped circular turbine inter-stages diffusers is performed using combined high-resolution RANS/ILES-method [1]. The method is based on the Roe scheme. High resolution is provided by the calculation of the parameters on the faces of the cells, which are necessary for the Roe scheme, with 5th order monotonic upwind finite-difference approximations. All calculations were performed on structured grids. The method of calculation previously has been successfully used for the calculation of separated flows in diffusers [2], for the study of synthetic jets [1, 3] and for the combined computational and experimental study of the effect of synthetic jets on the flow in a rectangular S-shaped diffuser [4].

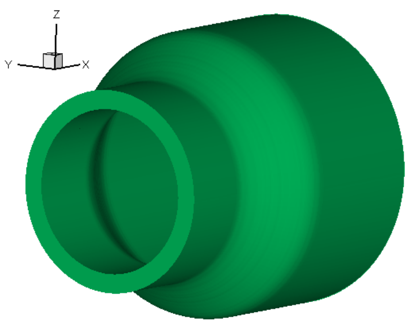


Fig.1

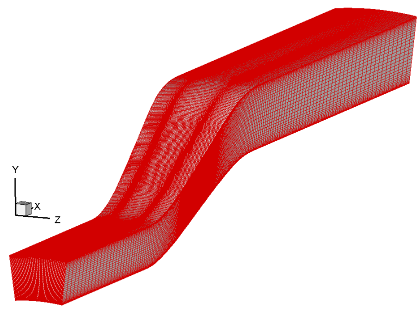
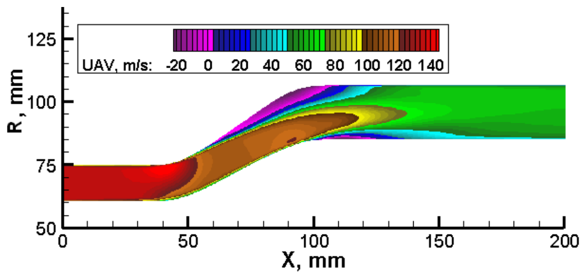
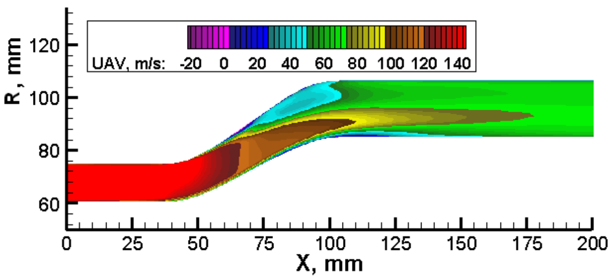


Fig. 2

Two variants of diffuser geometry were considered in this paper. The geometry of the first duct was close to the typical turbine inter-stages ducts of modern turbojet engine. View of the duct is shown in Fig. 1. Furthermore, was considered a so-called "aggressive" diffuser: the duct is 20% shorter then standard diffusser, but with the same ratio of the inlet and outlet areas. The calculations were performed on a grid containing 8.8×105 cells in both cases. An example of the computational grid is shown in Fig.2. In both cases of geometry calculations were performed for the basic diffusers without synthetic jets and for diffusers with the presence of synthetic jets. The computational domain is a channel sector 15 °. During calculations varied synthetic jets amplitude and frequency and their total number. Diffuser inlet velocity was 120-150m/s. In the calculations, it was found that the most effective position of synthetic jets is at the beginning of the separation zone, thus ensuring maximum impact on the stream.

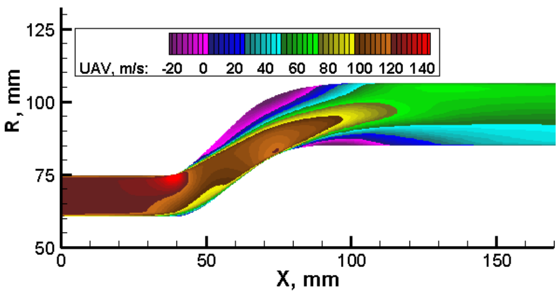
It was found that the presence of the synthetic jets reduces the total pressure losses at the outlet of the diffuser for almost all the test modes. This is due to the fact that the synthetic jets reduce or eliminate the separation zone in the diffuser by mixing high-speed main flow with low-speed flow in the separation zone. It was found that for both types of geometry diffuser increasing of synthetic jets frequency has little effect on the rate of losses of total pressure at the exit of the diffuser. Whereas, increase jet's amplitude in the investigated range (70-150m/s) significantly improves the flow characteristics: the level of total pressure losses at the outlet of the diffuser is significantly reduced. For example, for a standard diffuser with an amplitude of synthetic jets equal to150m/s losses rate is reduced up to 45%. Using synthetic jets in a standard diffuser is significantly reduced separation, the velocity field at the exit of the diffuser becomes more uniform (Fig. 3). The dependence of the level of longitudinal velocity fluctuations at the exit of the diffuser on the frequency of synthetic jets was obtained. It was established that peak value of the longitudinal velocity fluctuations at the top part of diffuser is reduced by 10-15% compared to the base case without jets. Depending on the frequency of synthetic jet static pressure fluctuations are reduced by 7-20% compared with the original diffuser. The increasing amplitude of synthetic jets with fixed frequency leads to reduction of the longitudinal velocity fluctuations. Fluctuations at the top of the duct is reduced by more than 2 times compared to the base case without jets at an amplitude 150 m/s. Static pressure fluctuations at the exit of diffuser also decrease with increasing amplitude of the synthetic jets. They are halved and become almost constant over the height of the duct when synthetic jets amplitude is 150m/s.

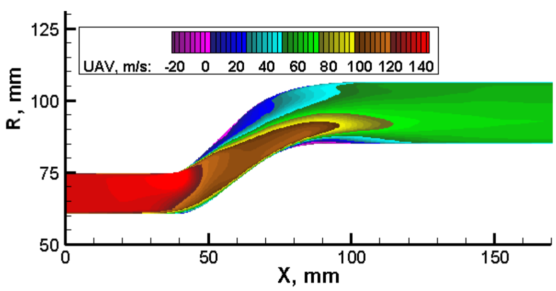




a b

Fig. 3. Averaged longitudinal velocity distribution in the longitudinal section of the standard diffuser a – without synthetic jets; b – with synthetic jets with an amplitude of 150m/s and frequency of 150Hz.





a b

Fig.4. Averaged longitudinal velocity distribution in the longitudinal section of aggressive diffuser a – without synthetic jet; b – with synthetic jets with an amplitude of 150m/s and frequency of 150Hz.

During the calculations of aggressive diffuser without synthetic jets it was established that its characteristics are poor in comparison with the standard diffuser: larger separation zone, increased total pressure losses at the exit of the diffuser. Fluctuations of the longitudinal velocity and the static pressure at the exit of diffuser non-monotonically depend on the frequency and amplitude of the synthetic jet. Level of static pressure fluctuations is reduced by 1.4 times. Total pressure losses in aggressive diffuser with synthetic jets with 150m/s amplitude are reduced by about 32% compared with an aggressive diffuser without synthetic jets. Averaged velocity field at the exit of diffuser are more uniform in comparison with aggressive diffuser without synthetic jets (Fig. 4).

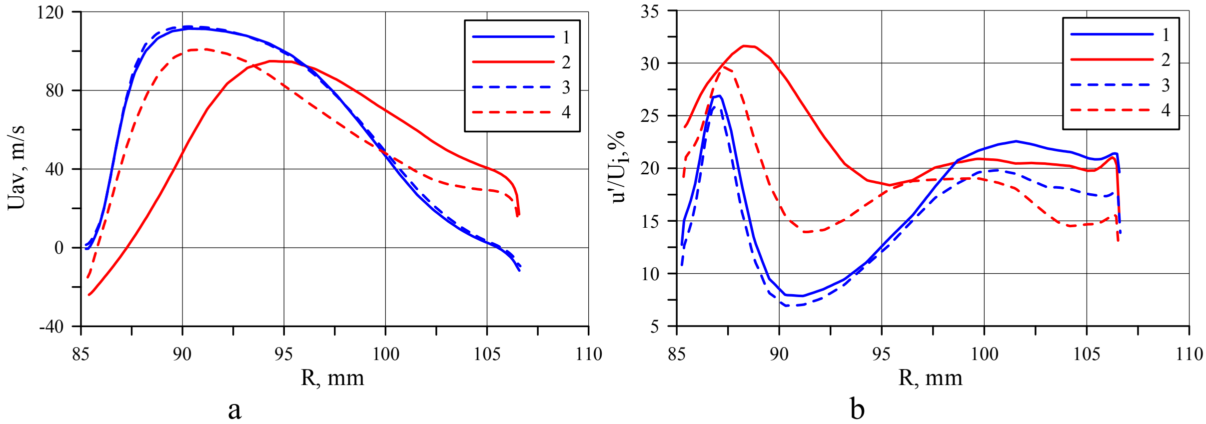


Fig.5. Distribution of the parameters at the exit of the diffusers a-full pressure, b-longitudinal velocity fluctuations. 1 – standard diffuser, 2 – aggressive diffuser, 3 – standard diffuser with synthetic jets with amplitude of 70m/s and frequency of 175Hz, 4 – aggressive diffuser with synthetic jets with amplitude of 70m/s and frequency of 175Hz.

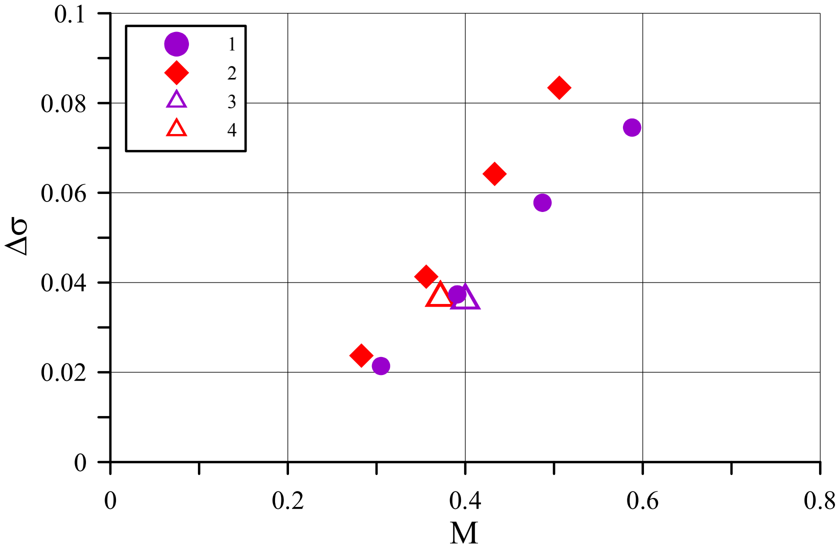


Fig.6. Losses of total pressure at the exit of the diffusers. 1 – standard diffuser, 2 – aggressive diffuser, 3 – standard diffuser with synthetic jets with amplitude of 70m/s and frequency of 175Hz, 4 – aggressive diffuser with synthetic jets with amplitude of 70m/s and frequency 175Hz.

Fig. 5a and Fig. 5b show the effect of synthetic jets with moderate amplitude 70m/s on the distribution of the parameters in the exit section of the standard and the aggressive diffusers. The amplitude 70 m/s can be achieved easily in the experiment [4]. In Fig. 5a it is shown that when synthetic jets are used, the velocity profile at the exit of aggressive diffuser comes close to the velocity profile of standard diffuser. The separation zones are substantially reduced. In Fig. 5b shows the distributions of the longitudinal velocity fluctuations in the output section of diffusers. Once again, level of fluctuations in aggressive diffuser decreases and becomes close to the level of fluctuations in the standard duct, and is even lower near the top wall of the diffuser when synthetic jets are present. Thus, the use of synthetic jets in an aggressive diffuser can significantly improve its performance. Characteristics of the flow at the outlet of this diffuser are almost equal and sometimes even better than ones for the standard diffuser. It is shown in Fig. 5. Dependence $\Delta\sigma = (1-\sigma)/\ \sigma$ from the Mach number M for the two variants of geometry is shown

in Fig. 6. Here σ is diffuser total pressure recovery coefficient. It is seen that the levels of total pressure losses of a standard diffuser and aggressive diffuser with synthetic jets are the same.
This work was supported by RFBR grant № 12-08-00951a.

References

1. Lyubimov D.A. Investigation of Impact of Jets with Zero-Net-Mass Flux on Flow in Curvilinear Diffusers. High Temperature, 2011, vol. 49, №4, pp. 557-567.
2. Lyubimov D.A. The Use of the Hybrid RANS/ILES Approach for the Investigation of Three Dimensional Separated Turbulent Flows in Curvilinear Diffusers. High Temperature, 2010, Vol. 48, No. 2, pp. 261–271.
3. D.A.Lyubimov, I.V.Potekhina Application of the high resolution ladge-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. 2012. Kazan. Russia. P. 180-181.
4. 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. 2012. Brisbane. Australia.