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INFLUENCE OF THE CASING TREATMENT DESIGN PARAMETERS ON THE DUCTED COUNTER ROTATING FAN NOISE

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The results of an experimental study of the effects of several slot type casing treatment (STCT) configurations on ducted counter rotating fan model (DCRF) noise are given in present work. The casing treatment design parameters such as lattice duty cycle and the cavity height were varied. It is shown that the most important parameter is the duty factor of the lattice. The configuration of STCT, which provides the greatest reduction of sum sound power level of the fan model was installed over the second rotor only and had the highest duty factor.

Keywords: Rotor, fan, noise, casing treatment, slot.

Nomenclature

DCRF – Ducted Counter Rotating Fan;
STCT – Slot Type Casing Treatment;
PWL – sound power level;
t_S –lattice spacing, mm;
δ_S – slot width, mm;
h – lattice height, mm;
H – height of the STCT cavity, mm;
D – duty factor of the lattice.

1. Introduction

Casing treatment (CT) of different configurations is widely used as a mean of increasing gas-dynamic stability of compressors. One of the most successful development of such device is a slot type casing treatment (STCT) installed over the rotor [1]. Experimental studies have shown high anti-surge, anti-stall and anti-flutter properties of slot type casing treatment, as well as a number of other advantages [2].

At optimal regimes of flow in the rotor at increased airflow rates the pressure in front part of blade-to-blade channel does not exceed the pressure downstream the front rotor tip and the leakage of air flow from the flow path inside the CT does not occur. On the contrary, at not optimal flow regimes may occur air flow leakage through the grid and ring cavity inside the rotor flow path. When decreasing the air flow rate through the compressor the increased pressure downstream the compressor or local reduction of tip flow velocity upstream the rotor flow path occur the increase of the blades angle of attack, the pressure in front part of the blade-to-blade channel increases and becomes higher than the pressure at the tip of the compressor flow path upstream the rotor. Under the action differential pressure starts the leakage of air flow through the slots of CT installed above the rotor into the annular cavity, and from it into the flow path of the rotor. As a result at the flow path tip the circulating flow is generated, the circulating air flow rate increases with an increase in back pressure downstream the rotor, therefore the angles of attack on the blades changed little.

Using a lattice of slope slots in the direction of rotor rotation promotes intensification of the circulation flow. The intensification of the circulating flow facilitates the use of a lattice with a slope of slots in the cross section in the direction of rotation. This happens due to the fact that at the air flow leakage from the annular cavity through the slots into the flow path of the rotor the flow gets a swirl in the direction opposite to the direction of rotor rotation, which increases the suction ability of rotor tip area and increases the pressure. Thus, the ring cavity serves as a bypass duct, transferring the return circulating flow of air from the rotor when the pressure increases, followed by above a maximum value, preventing release directly from the rotor into the flow path upstream. In addition, the ring cavity facilitates alignment of the circumferential pressure non-uniformity and prevents the formation of discrete separation zones as well as minimizes the flow pulsations caused by the intersection of the slots of the rotating blades.

Reference [3] presents a methodology for casing treatment design on the base of which developed CT demonstrated a significant increase in surge margin when testing at axial low-pressure compressor.

Under the guidance of prof. R.A. Shipov a number of studies on the effect of STCT on the fan noise was carried out at CIAM Russia in 2001-2006 [4]. The results of the experiments on the model of fan confirmed that at low circumferential velocities CT of slot type effectively reduced noise in a wide frequency range 1 – 8 kHz, at that noise level in some third octave frequency bands were decrease on 5-6 dB.

In further work in CIAM, it was investigated the influence of casing treatment on noise of counter rotating fan model of 22” diameter [5]. It was the variant of the STCT with a number of slots equal to 85. Three STCT configurations were tested: STCT installed in the casing of the fan model above the first rotor, above the second rotor and over both rotors at the same time. Positive impact of STCT on noise levels of counter rotating fan model appeared when installing it over second rotor and over both rotors, with the maximum reduction of noise level of 4-6 dB at a frequency of 2 kHz. The installation of STCT above the first rotor turned out to be not effective. At the same time, the combined effect of STCT installed over R1 and R2 led to the reduction of noise by 2-7 dB in a wider frequency range than with the installation of the STCT only over the second rotor.

The presented work describes the results of investigation of influence of several STCT configurations on the noise of counter rotating fan model when the STCT design parameters, such as the duty factor of the casing lattice and the height of the cavity, were varied within easy access.

2. Experimental object

Tests were carried out on the bench, which includes a large anechoic chamber [6-7]. The fan model is located inside the anechoic chamber. The test bench construction and the test object location allow determining its acoustic performance in front and rear hemispheres simultaneously.

Air inflow enters the anechoic chamber through a hole in the floor at a distant wall of the chamber (in relation to the main casing) occupying total width of the chamber and used for installation of a suction system and an air filter. To avoid initiation of strong vortex flow, causing distortion in test model aerodynamic and acoustic characteristics, the suction of exhaust air flow through the inlet cone is provided by means of technological exhauster machines. At air suction rate exceeding on 1.5÷2 times air flow rate through the fan, intensity of vortexes inside the anechoic chamber is negligible, air flow velocity does not exceed 3÷5 m/s and exhaust vortexes does not recirculate to the fan inlet. At increasing of total airflow rate the number of vortexes raises, their velocity increases as well, which leads to the growth of turbulence level and energy loss. At decreasing of total airflow rate till the value close to the airflow rate through the fan, vortexes reach the fan inlet and their sizes increase at rear hemisphere also. As a result the necessity of the anechoic chamber “ventilation” during fan model experiments was revealed.

However the measurements showed, that the exhaust system from the anechoic chamber is itself power noise source. With the aim of exhaust system noise reduction the cone walls were covered by sound absorbing treatment, the inlet cross section was changed in order to avoid flow separation, generating additional aerodynamic noise. Besides for airflow velocity reduction the cross section square of the tube scroll was increased. As a result of these arrangements on the background exhaust machine noise reduction the relationship «useful signal/background noise» considerably changed. At forward hemisphere the background exhaust machine noise masks the useful signal in low frequency range up to 400 Hz. Within the frequency range 400-2000 Hz fan noise levels need corrections taking into account the relationship «useful signal/background noise». In the range over 2 kHz influence of exhaust machine noise on overall noise level should be neglected. At rear hemisphere exceeding of useful signal over background noise becomes significant in frequencies, lower than 400 Hz. Thus the anechoic chamber is available for performing of the acoustic measurements of fan models within the operating range from 400 up to 40k Hz [4].

In order to obtain the uniform inlet flow turbulence control screen (TCS) was designed. TCS decreases significantly the level of inlet flow turbulence non uniformity accompanied by tonal fan noise reduction on 8-10 dB. Calibration tests of TCS showed that insertion error of acoustic measurements does not exceed ±0.5 dB within the whole operating range [4].

Tests have been performed on ducted counter rotating fan model with diameter of 22″. Its case was adapted for casing treatment installation (Figure 1).

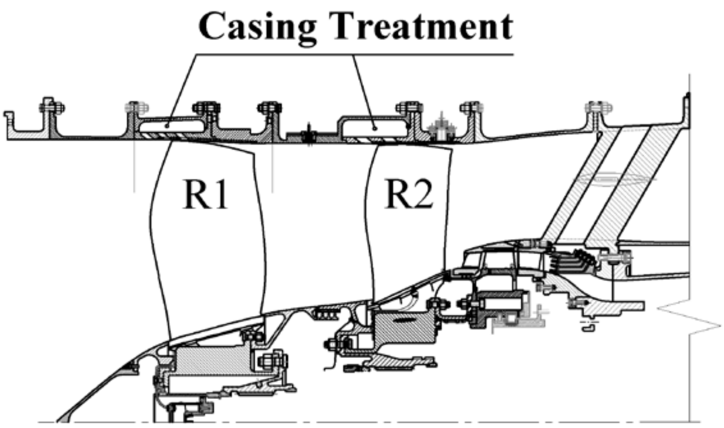

Figure 1: Cross-section of ducted counter rotating fan model.

The choice of STCT design parameters is based on the results of aerodynamic calculations taking into account the mechanical and technological properties of turbomachines. According to the empirical methodology of STCT design [3] based on large amount of experimental data were selected design parameters of slot type casing treatment.

Figure 2: Slot type casing treatment.

The reference configuration "E" was designed according to the empirical methodology. Parameters of the others configurations were chosen based on the results of 3D optimization stationary calculations of the performances of DCRF equipped with the STCT [3].

The experimental program included six configurations of the STCT (see table 1), five configurations were installed only over the second rotor and five other configurations – above both rotors.

In the given series of experiments two dimensionless STCT design parameters – the lattice duty factor (D) and the dimensionless height of cavity ($\overline{H}$) – were varied.

The lattice duty factor is determined by analogy of electric pulse as the relation of the slot width δ_S (pulse width) to the lattice spacing t_S (pulse period) [8]. The duty factor was varied from 0.25 up to 0.68 (Table 1). The further increasing of the duty factor is not appropriate for the reasons of STCT construction strength. The dimensionless cavity height $\overline{H}$ is determined as the relation of the cavity height H to the STCT overall height.

$$D = \delta_s/t_s; \quad (1)$$

$$\overline{H} = H/(H+h). \quad (2)$$

Table 1: Design parameters of tested STCT configurations

Configuration	РК I	РК II	Z	$\overline{H}$	D
A	–	+	42	0.71	0.25
B	–	+	85	0.71	0.50
C	–	+	85	0.53	0.50
D	–	+	85	0.33	0.50
H	–	+	115	0.71	0.68
J	–	+	115	0.62	0.68
E	+	+	133; 85	0.65; 0.71	0.5; 0.5
F	+	+	133; 85	0.65; 0.71	0.5; 0.5
G	+	+	66; 85	0.65; 0.71	0.25; 0.5
M	+	+	133; 115	0.65; 0.71	0.5; 0.68
N	+	+	133; 42/42	0.65; 0.62	0.5; 0.15/0.15

3. Experimental results

The decrease in total sound power level (ΔPWL) of fan model is used for the purpose of assessing the STCT acoustic efficiency at runway, flyover and approach modes.

Figure 3 shows the comparison of DCRF sound power level when the STCT is absent and when it is installed only over the second rotor. There were six such configurations: A, B, C, D, H, J. It is clearly seen, that the acoustic efficiency is increased with growth of lattice duty factor at all considered fan modes. It is necessary to notice, that when the duty factor is 0.25, at flyover and approach modes the STCT installation, instead of expected fan noise reduction, leads to its significant generation that is unacceptable for practical use.

Figure 4 shows the relation of a sum sound power level reduction of DCRF from casing treatment lattice duty factor at identical values of other design parameters, including cavity height. It is obviously, that the STCT acoustic efficiency increases linearly with growth in the lattice duty factor.

Figure 5 shows acoustic efficiency of different configurations with varying cavity height and with STCT placed over the second rotor. The height of the cavity does not significantly affect the STCT acoustic efficiency, in contrast to the lattice duty factor; however, within the range of variation with the cavity height increasing, the STCT acoustic efficiency also increases.

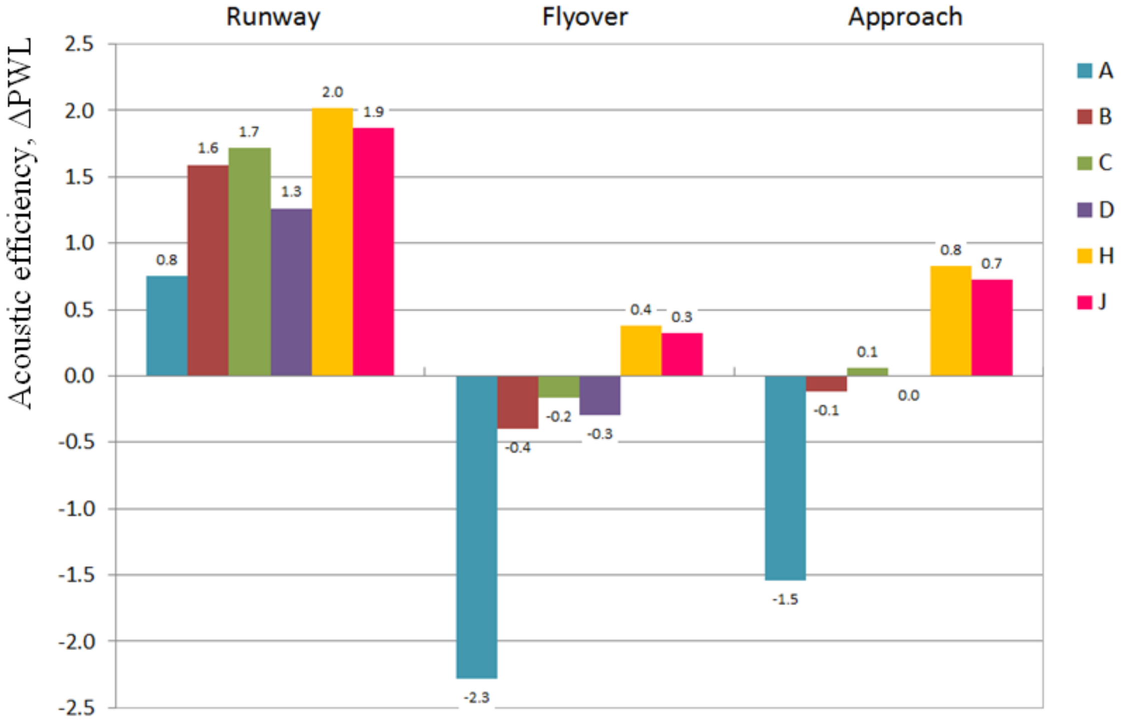

Figure 3: Acoustic efficiency of casing treatment configurations installed only over the second rotor.

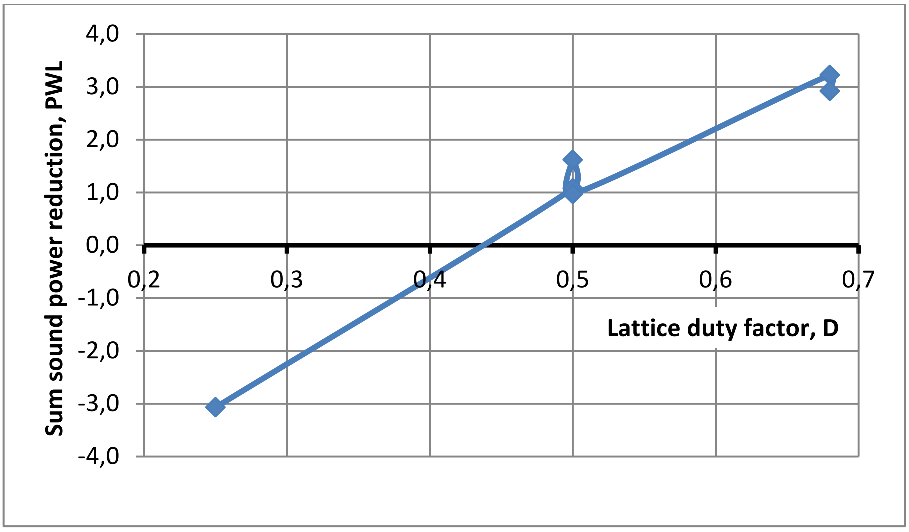

Figure 4: Dependence of the sum sound power level reduction relative the lattice duty factor.

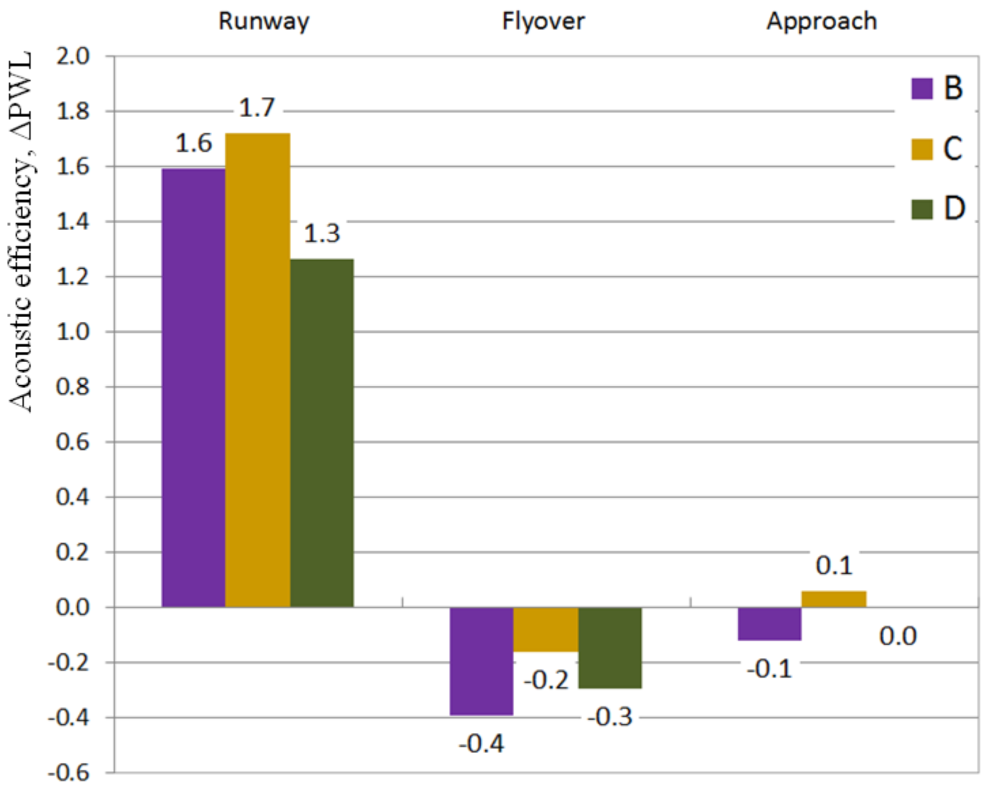

Figure 5: Acoustic efficiency of casing treatment configurations at different cavity height of STCT.

The comparison of DCRF sound power levels without STCT and with STCT installed over both rotors is showed at figure 6. There were five such configurations (see Table 1). It can be seen that of these configurations, the best configuration is "M", which contains the casing treatment over the second rotor with the highest lattice duty factor, and the worst one is the "N" configuration containing the casing treatment over the second rotor with the smallest lattice duty factor.

Figure 7 shows comparison of acoustic efficiency of configurations with the STCT installed only over second rotor and configurations with the STCT installed over the both rotors. Let's compare in pairs the decreases in sound power levels of the fan at installation of configurations «B» with «E» – both have the STCT over the second rotor with duty factor 0.5 – and «H» with «M» – both have the STCT over the second rotor with duty factor 0.68. Obviously, the configuration including two STCT placed over both rotors, appears less acoustically effective, than configuration with STCT, placed only over the second rotor. Thus, the "E" configuration is less effective by 1.0 dB relative to the "B" configuration, and the "M" configuration is less effective by 1.1 dB relative to the "H" configuration.

Probably, this unexpected phenomenon is because that the casing treatment has favorable effect on the flow in blade-to-blade space. In this sense the second rotor is in conditions of a disturbed flow from first rotor and the STCT installed over the second rotor promotes to reduce these flow disturbances. The more uniform flow comes to the first rotor and interaction between this flow and first STCT leads to reverse effect, i.e. to appearance of aerodynamic disturbances. As a result the aerodynamic disturbances lead to additional generation of noise.

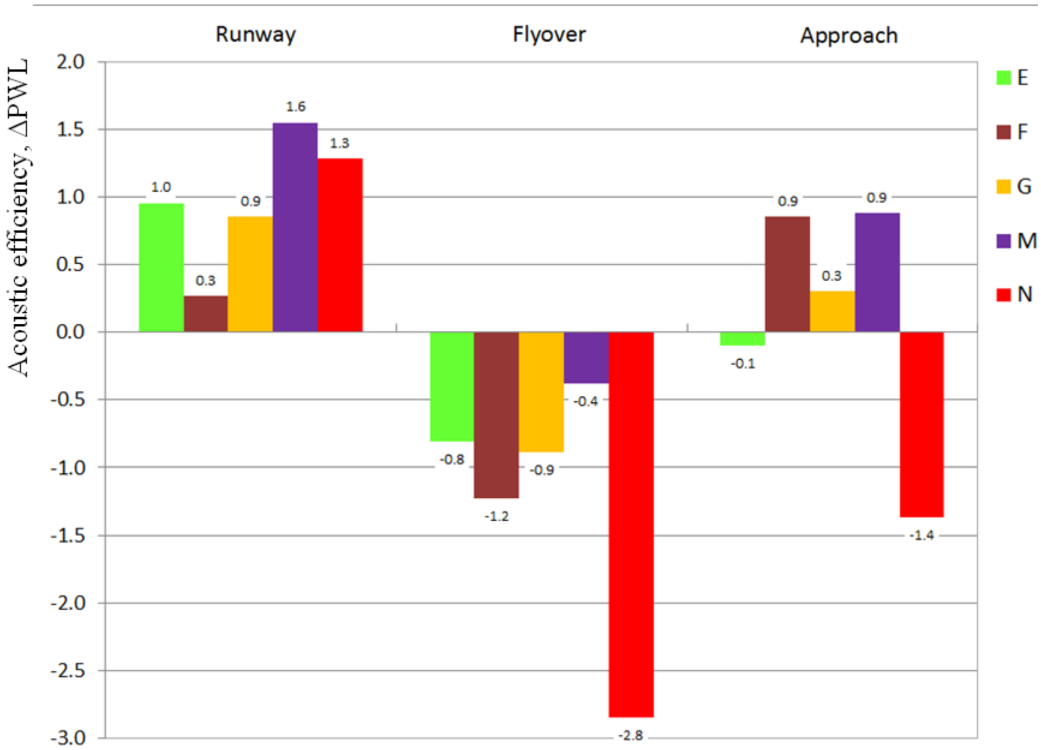

Figure 6: Acoustic efficiency of casing treatment configurations installed over both rotors.

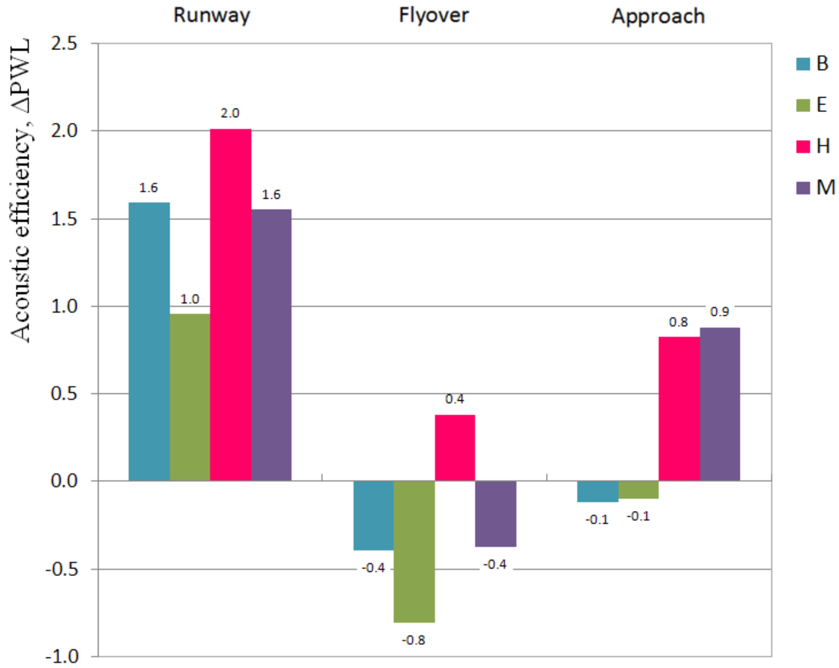

Figure 7: Comparison of acoustic efficiency of the casing treatment configurations, installed only over the second Rotor and over both Rotors.

4. Conclusions

Study of the slot type casing treatment as a silencer of has been performed. Test program included seven STCT configurations: six of them were installed over the second Rotor and another five ones – over first and second rotors simultaneously.

It has been found that for the ducted counter rotating fan, the configurations with STCT installed only over the second rotor are more acoustically efficient than the configurations with STCT installed over both rotors.

For the STCT configurations installed only over the second rotor were shown that in terms of acoustic efficiency the most significant STCT design parameter is. The varying of the lattice duty factor from 0.25 to 0.68 leads to increasing of the sound power level reduction by 6 dB. The further duty factor increasing may cause a loss of the lattice strength. The cavity height is also the design parameter that affects the STCT acoustic efficiency, but it influence is not so significant in contrast to the lattice duty factor. It was found, that within the range of variation as the cavity height increases, the STCT acoustic efficiency increases too.

5. References

1 Gelmedov F.S., Lokshtanov E.A., Olshtein L.E., Sidorkin M.A., Russian Federation, "Anti-Stall Tip Treatment Means", European Patent specification # EP 0688 400 B1, (1997).

2 Greitzer E.M., Nikkanen J.P., Haddad D.E., Mazzawy R.S., Joslyn H.D., A Fundamental Criterion for the Application of Rotor Casing Treatment, *Trans. ASME J. Of Engineering for Power*, (1979), v. 101, 237-243.

3 Gelmedov F.Sh., Mileshin V.I., Kozhemyako P.G., Orekhov I.K., Stall Margin Improvement in Three-Stage Low Pressure Compressor by Use of Slot Type Casing Treatments, *Proceedings of GT2014 ASME Turbo Expo,* June 16-20, Düsseldorf, Germany, *GT2014-26298* , (2014).

4 Povarkov V., Khaletskiy Yu., Shipov R., The Effect of Casing Treatment on the Scale Fan Noise, *Proceeding of the 12th International Congress on Sound and Vibration,* Lisbon, Portugal, (2005).

5 Iurii Khaletskii, Victor Mileshin., Experimental study of casing treatment impact on ducted counter-rotating fan noise, *Proceedings of the 22nd International Congress on Acoustics, Buenos Aires, Argentina, Paper 2016-108, (2016).*

6 Khaletskiy Yu., Mileshin V., Shipov R., New acoustic facility for testing universal propulsion simulators, *Proceeding of the 13th International Congress on Sound and Vibration*. Vienna, Austria, July 2-6, (2006).

7 Korjnev V.N., Povarkov V.I., Khaletskii Iu.D., Methodological problems of fan models noise measuring in the anechoic chamber of C-3A CIAM test bed, *Environmental challenges of aviation*/edited by Iurii Khaletskii. – M.: Torus press, (2010), pp. 83-100.

8 Barrett, Steven Frank; Pack, Daniel J., *Timing subsystem. Microcontrollers Fundamentals for Engineers and Scientists*, Morgan and Claypool Publishers. pp. 51–64. (2006), ISBN 1-598-29058-4.