IOP Conf. Series: Materials Science and Engineering **208** (2017) 012032 doi:10.1088/1757-899X/208/1/012032

# Aeroacoustic investigations of subsonic jet in PNRPU anechoic chamber

**V V Palchikovskiy[a], I V Khramtsov, V V Ershov, D A Gornova, A A Selivanova**

Perm National Research Polytechnic University, Perm, 614990, Komsomolsky prospect, 29, Russia

E-mail: [a] vvpal@bk.ru

**Abstract**. A study of the aeroacoustic characteristics of the PNRPU jet rig is considered. The design of the jet rig is described. The velocity of the jet along the axis is measured at a certain distance from the nozzle exit section. The comparison of the velocity with a semi-empirical model is performed. A good agreement of the velocities is observed. The noise of the jet is measured for different velocities in the direction of 30 and 90 degrees. The obtained spectra are compared with the results of measurements of the jet rig in the anechoic chamber AC-2 TsAGI. Localization of the noise sources of the jet with the Bruel & Kjaer microphone array is also carried out. The investigations are carried out in a new anechoic chamber at PNRPU.

## 1. Introduction

The noise of an aircraft engine jet makes a dominant contribution to the overall noise of the aircraft at take-off [1]. The development of effective measures to reduce this negative impact requires a more thorough study of the noise generation by turbulent flows. The basic mechanisms of these processes are studied with model jets. In order to carry out such studies in laboratory conditions, the availability of an anechoic chamber is primarily required, where it is possible to carry out acoustic measurements in free field conditions. Then, it is required experimental rig that supplies air turbulent flow into the anechoic chamber. In 2014-2016, these facilities were created at the Perm National Research Polytechnic University (PNRPU). The qualification tests have shown that the anechoic chamber allows the acoustic measurements to be performed to obtain quantitative results [2]. However, it is also required to investigate the aeroacoustic quality of a subsonic turbulent jet.

## 2. Jet rig

The availability of a jet rig in the anechoic chamber gives a wide field for aeroacoustic research. However, chose of the jet type is largely related to the financial possibilities, as well as the availability of the necessary rooms for the installation of the entire supply-exhaust system of the jet rig. For example, a supersonic jet with a cocurrent flow requires the powerful compressed air sources and a developed network of air ducts to deliver the air flow into the chamber and exhaust it [3]. The hot jet complicates the design of the anechoic chamber as a whole [4]. To implement jet noise study in the research university, a cold submerged jet can be chosen [5].

Also the key issue is choosing the type of compressed air source. As a rule, these are compressor units that pre-pump special vessels with high pressure and carry out pumping air into the vessel during the experiment. A simpler, but rare, variant is to use a fan to supply the jet into the anechoic chamber [6]. This method does not require the use of pressure vessels, it allows continuous supply of air for a long time (several hours) at the maximum flow rate, while the preparation time for testing is minimal (1-2 minutes). However, there are also disadvantages; in particular, it is necessary to provide protection from the penetration of the fan unit noise into the anechoic chamber through the air ducts. In connection with the factors listed above, a variant of the submerged cold jet was chosen in PNRPU, the supply of which into the anechoic chamber is carried out by fans.

The diagram of the supply-exhaust system of the jet rig is shown in figure 1. Two fans in tandem with a power of 45 kW each allow to accelerate the jet to 0.7 M. The fans are controlled programmatically via frequency converters, which allows smoothly adjusting velocity of the jet. To prevent penetration of the fan noise into the anechoic chamber, mufflers are provided in the air duct net. In the anechoic chamber, a plenum chamber with circular muffler (there are 3 layers of sound-absorbing material inside it) is mounted before the nozzle. This gives an additional reduction in fan noise. The measurements of the jet velocity with and without the plenum chamber have shown that it does not affect the magnitude of the velocity.

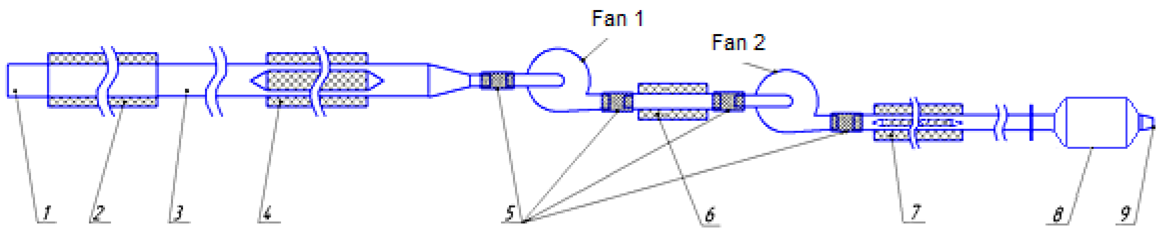



**Figure 1.** Diagram of jet supply-exhaust system.
1 – inlet via collector; 2 – muffler; 3 – air duct; 4 – circular muffler; 5 – flexible joint;
6 – muffler; 7 – circular muffler; 8 – plenum chamber with circular muffler; 9 – nozzle.

## 3. Measurements of the jet velocity

The study of aeroacoustic characteristics of the jet is primarily required to begin with a study of jet velocity, since its correct determination significantly affects the accuracy of the results in estimating the levels of the sound pressure generated by the turbulent jet. In this study the jet velocity was measured with Pitot-Prandtl tube. The tube was installed at a different distance from 0 to 20 nozzle-exit diameters. At the first 0.4 m, measurements were taken every 0.05 m, then every 0.1 m.

The evaluation of the results was carried out by comparing the measured velocity with the semiempirical model, which makes it possible to estimate the velocity on the axis of the jet at Mach number M = 0.28 [7]:

$$\frac{U}{U_j} = 1 - \exp\left(\frac{6.5D}{4.1D - X}\right) \quad (1)$$

where $U$ is jet velocity at measuring point; $U_j$ is velocity at nozzle exit section; $D$ = 0.04 m is nozzle-exit diameter; $X$ is distance from nozzle exit section.

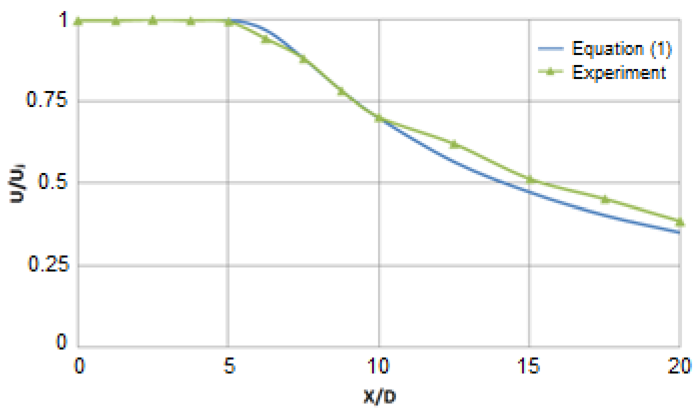



**Figure 2.** Comparison of the experimental results and the semiempirical model.

As can be seen in figure 2, the velocity distribution on the axis of the jet is in good agreement with the semi-empirical model, especially in the region of 5-10 nozzle-exit diameters, where the location of the jet noise source is expected. The initial region of the jet where the velocity is constant is approximately 5 nozzle-exit diameter. Discrepancy in the region of 10-20 nozzle-exit diameters does not exceed 5% and can be caused, both by the measurement errors, and by the flow conditions in the anechoic chamber.

## 4. Measurements of the jet noise

The next important study in the estimation of the aeroacoustic quality of the turbulent jet was the measurement of its noise in the far field. The measurements were performed with a microphone ½" Bruel & Kjaer 4192-C-001. The microphone was installed at a height of 2.5 m from the surface of the hard floor, which corresponds to the height of the jet rig axis. The floor of the anechoic chamber was covered with sound-absorbing wedges when measuring the noise. Measurements were made in the direction of 30 and 90 degrees relative to the axis of the jet, at a distance of 4.6 m and 2.3 m from the nozzle exit section. Position of the microphone in anechoic chamber when measuring the noise of the turbulent jet in the direction of 30 degrees is shown if figure 3.

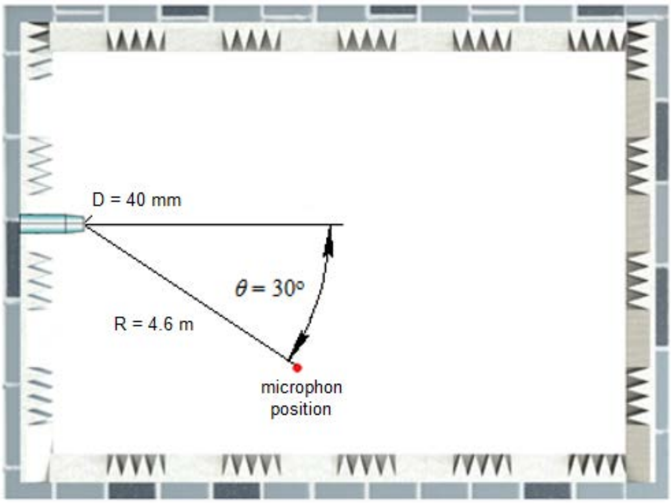



**Figure 3.** Position of the microphone in anechoic chamber when measuring the noise of turbulent jet.

In order to evaluate the possibility of measuring the noise of the turbulent jet in the anechoic chamber, the obtained measurement results had to be compared with the known results of similar tests in another anechoic chamber. For this purpose, it was used the results of measurements in anechoic chamber AC-2 TsAGI, which were performed for the jet rig with nozzle diameter D = 40 mm with a 6-microphones array of 0.85 m radius (figure 4) within the investigation of the azimuthal decomposition of turbulent jet noise [8]. From the data set, the points with coordinates $\theta = 30°$, R = 1.7 m and $\theta = 90°$, R = 0.85 m were taken. To perform the comparison, the sound levels obtained in the PNRPU were calculated to the points corresponding to the measurements in the AC-2 TsAGI. The power spectral density (PSD) for noise of the jets with the similar velocities is shown in figure 5.

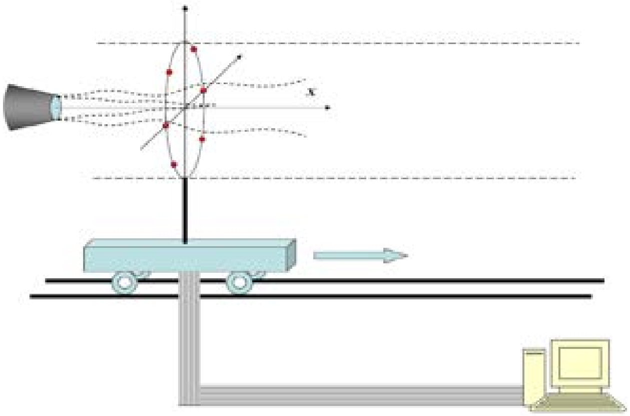
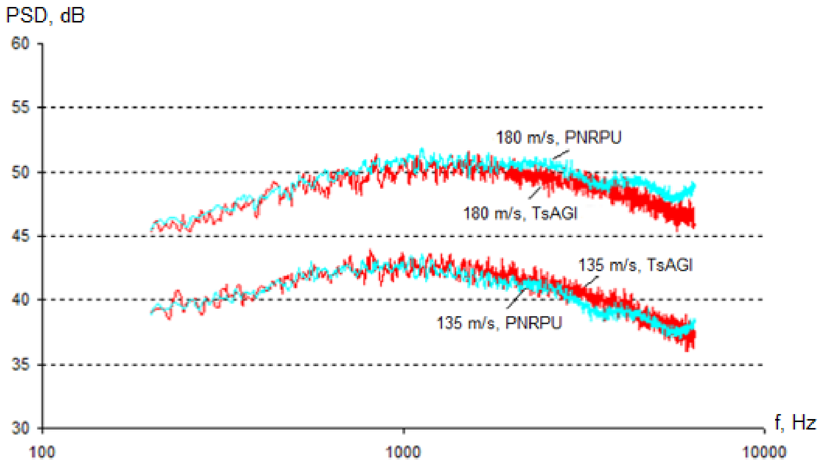
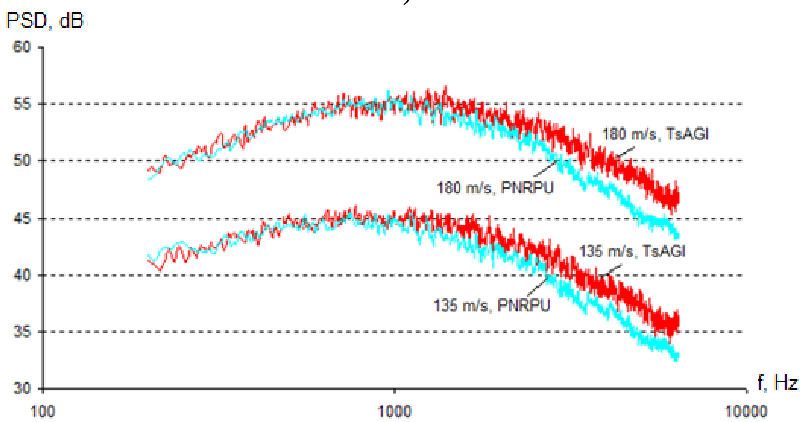



**Figure 4.** Diagram of jet noise measurements in anechoic chamber AC-2 TsAGI.




a)




b)

**Figure 5.** Power spectral density for the similar velocities of PNRPU and TsAGI jet rigs a) at angle 30$^o$, b) at angle 90$^o$.

It can be seen that, in general, the noise spectra of the jet obtained in the anechoic chamber of the PNRPU are qualitatively similar to the spectra of AC-2 TsAGI. Oscillations in the noise spectrum of the jet rig at the frequencies above 3500 Hz may be because the microphone was mounted on a stand without a long holder, so that at high frequencies the reflections from the microphone stand have a significant effect on the quality of measurements.

IOP Conf. Series: Materials Science and Engineering **208** (2017) 012032 doi:10.1088/1757-899X/208/1/012032

## 5. Localization of the jet noise source

Additional information on the quality of the noise generated by the jet rig can be obtained by localizing the noise source: in good quality subsonic jet the noise source is located on the axis of the jet at a distance of 5-6 diameters from the nozzle-exit section. For the localization of the noise sources a 9-armed 54-microphone array of Bruel & Kjaer was used. The microphones arrangement in the array are optimized for the dynamic range, the level of phantom sources is less than 9-15 dB the maximum noise source level at this frequency (frequency band). The measurements use Bruel & Kjaer 4944-W-008 microphones. The received signals are transferred from microphones to analyzers Bruel & Kjaer 3055-B-120 with a frequency range up to 25.6 kHz, and then to the specialized software PULSE.

This software allows performing calculations to localize acoustic sources in a given frequency range using the beamforming method [9]. The main idea of the beamforming method consists in coherent summation of the measurement results from various microphones to improve the signal emitted from the focal point and minimize the contribution of signals from all other points. Thus, the beamforming method is a method of summation of data measured by microphones to determine the spatial distribution of noise sources.

Figure 6 shows a photo of the experiment (left) and some localization results of the noise sources in turbulent jet (right) obtained by beamforming method. The localization was carried out with a dynamic range of 6 dB, i.e. the sources with an acoustic pressure of 2 or more times less than the maximum are not shown. The obtained results demonstrate that the source is located on the axis of the turbulent jet at a distance of 5-6 nozzle-exit diameters. This result also indicates a good quality of the jet rig.

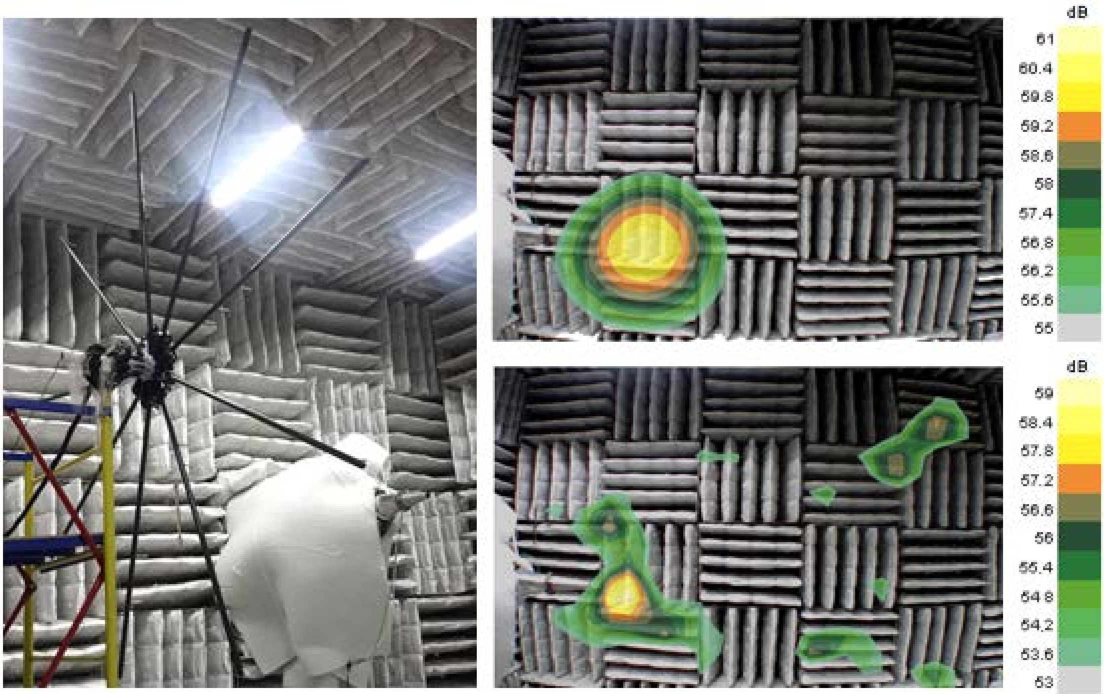



**Figure 6.** Localization of noise sources at frequency of 800 and 2000 Hz at jet velocity of M=0.5.

## 6. Conclusion

The following conclusions can be drawn as a result from the current study.

1. Velocity distribution on the axis of the jet is in good agreement with the semiempirical models, which is important for the correct quality of jet noise generation.
2. Source of noise in the jet is located at the initial region of the jet at a distance of 5-6 nozzle-exit diameters, which is typical for the noise of turbulent jets.

3. Noise of the jet in the far field in the direction of 30 and 90 degrees is in good agreement with the noise of the jet rig in AC-2 TsAGI.

Thus, the created jet rig in the anechoic chamber of PNRPU has a good aeroacoustic quality and makes it possible to carry out studies of the noise of turbulent flows, the jet-obstacles interaction noise, and testing passive and active methods for controlling the noise of turbulent jets.

**Acknowledgments**
The authors are grateful to Prof. V.F. Kopiev for providing experimental data obtained on the anechoic jet rig AC-2 TsAGI.

Results have been obtained in the framework of the government task “Researchers working in scientific laboratories created by the government program “Megagrants”, contract No. 9.8130.2017/P220.

Experiments were carried out on unique scientific installation “Acoustic anechoic chamber with aerodynamic noise sources”.

**References**

[1] Leylekian L, Lebrun M and Lempereur P *Journal Aerospace Lab*. 2014 **7**
[2] Kopiev V F, Palchikovskiy V V, Belyaev I V, Bersenev Yu V, Makashov S Yu, Khramtsov I V, Korin I A and Sorokin E V *Acoustical Physics*. 2017 **63** 114-126
[3] Anechoic jet rig AC-2 TsAGI, http://www.tsagi.ru/experimental_base/akusticheskaya-kamera-ak-2/
[4] Ahuja K K *AIAA Paper*. 2003 **706**
[5] Bridges J E and Hussain A K M F *Journal of Sound and Vibration*. 1987 **117** 289-311
[6] Guj G, Camussi R, Carley M, Ragni A, D’Alessio T and Bosi M *AIAA Paper*. 1998 **2358**
[7] Lau J C, Morris P J and Fisher M J *Journal of Fluid Mechanics*. 1979 **93** 1-27
[8] Kopiev V F, Zaitsev M Yu, Velichko S A, Kotova A N and Belyaev I V *AIAA Paper*. 2008 **2887**
[9] Johnson D H and Dudgeon D E Array signal processing: concepts and techniques (Prentice - Hall, Upper Saddle River, NJ) 1993 p 537