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# GTM-120 micro gas turbine engine noise identification

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*Micro gas turbine engines are a popular subject in research activities; most of them consider performance measurements and vibration analysis, which are related to operating running engines. Operating even small-size engines causes potential risk to operator health. The research problem was to identify the acoustic flow field from the front and back of an operating GTM-120 engine. Research was divided into three parts: identify noise at various rotational speeds, identify the acoustic field of the engine, and identify noise levels at additional points. Obtained results identifies noise, from such a small engine, is at a range of 67 to 109 dBC, which is harmful and unpleasant to people that are within a radius of 15 meters from the engine. The final conclusion is that installing a muffler for any size of turbomachinery should be mandatory.*

Key words: *acoustics, noise, jet engine, micro, compressor, turbine, hearing, health*

## 1. Gas turbine and micro gas turbine engines noise

The noise spectrum in a gas turbine engine is unique, with characteristics that are a result of the engine design and its operation. All engine components (i.e. fan, compressor, combustor, turbine, and exhaust system) contribute to the overall broadband noise. In comparison to piston engines, gas turbine engines are continuous cycle engines that take place simultaneously in all stages of the Bryton cycle. The relative noise level for individual sources will vary not only due to different engine operating conditions. Turbine noise can be associated with two categories: internally generated noise, usually resulting from the operation of rotating engine parts, and externally generated jet noise. Noise sources are strictly related to engine design form. For example, in high-flow turbofan engines, the fan is responsible for the noise generation. It's size and airflow are up to five times greater than the airflow through the engine core. Noise generated by the fan and compressor propagates throughout the intake duct and the engine inlet that is going through the front of the engine. Noise from the combustor and turbines exits the engine through the jet pipe.

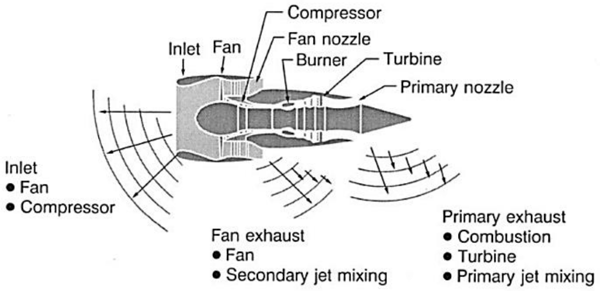

Fig. 1. Turbofan engine noise sources [1]

Figure 1 presents the main sources of noise in a turbofan engine, along with the direction of noise emissions.

### 1.1. Internal noise – turbomachinery noise

Internal noise generated by rotor components is similar and largely depends on the rotor tip blade speed. They vary based on the speed of sound criteria – Mach number M. For subsonic blade tip speeds regime, the main source of noise is pressure pulsations on the blade profiles that arise from the turbulent airflow. At static conditions, random changes in the pressure and velocity of the intake air can be observed resulting from natural atmospheric turbulence or turbulence caused by nearby structures. The compressor intake section composition – depending on engine layout (turbofan, turbojet, turboprop) – adds to the complexity of the obtained acoustic spectrum. Operating at flight conditions, airflow is more uniform – less turbulent. Rotating at supersonic speeds, the source of noise is shock waves generated at the edges of the blades. The distance between the turbomachinery stages also affects the generated noise. The combustor is a generator of engine noise. Noise, from the combustor, passes through the jet pipe. It is not an easily distinguishable component. The acoustic spectrum assigned to the combustor is very similar to that of the mixing streams, which makes it easy to confuse them. For angles corresponding to the angles of refraction propagating from inside the engine through to the jet mixing area, it is possible to determine both the level change and the distinct spectral shape associated with combustion and other internal sources. Generated noise is the result of very turbulent processes taking place in the combustion chamber. In other cases, it is the result of changes in the temperature of gases leaving the combustion chamber which affects other engine components – turbine, and jet pipe generated noise. No one has developed a definitive predictive procedure that considers all the observed features of gas turbine engines [17]. Micro gas turbine noise tests have shown that the noise level remains at 80 dB. It should be considered that the presented MGT (micro gas turbine) was based on a turbocharger. Radial turbines have lower rotational speeds that would significantly lower noise emissions [11].

### 1.2. External noise

Jet noise is related to the process of mixing exhaust gases with the atmosphere. Sound sources related to impact noise in an ineffectively expanded supercritical stream (Fig. 2). For engines operating at subcritical flow speeds, the generated noise will only concern the processes of mixing the exhaust stream with the atmosphere. The vortices affecting the mixing process vary significantly as they move away from the outlet nozzle (growing along the stream and losing speed). For engines reaching supercritical flow speeds, shock noise is superimposed on stream mixing noise as a secondary source [17].

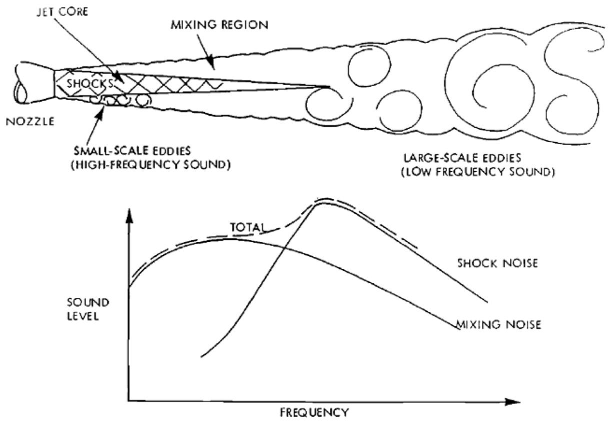

Fig. 2. Source of jet noise [1]

The most important factor influencing the noise, resulting from the mixing of exhaust gas streams with the atmosphere, is the velocity of the flowing exhaust gases. A second factor that also affects the overall noise is the exhaust gas temperature. The noise level will increase with the mass air flow (proportional to air density). The effect of speed can only be roughly estimated by taking the exhaust gas velocity value. For high exhaust gas velocities (approx. 400–500 m/s), the intensity of the emitted noise increases with the eighth power of the exhaust velocity; for low velocities (approx. 200 m/s), the intensity increases with the second power. Conventional turbojet engines are characterized by small cross-sections, relatively low air mass flow, and very high exhaust gas velocities. For them, the dominant sound source was the exhaust gases mixing with the surroundings.

### 1.3. Methodology and testing

Measurement methods for turbine engine acoustics are carried out for the purpose of creating engine acoustic models. The data collected in this manner can be used for engine certification or for further design modification. The most well-established method of collecting data for the purpose of creating an acoustic model of an engine is the empirical method. The noise spectrum obtained during engine testing contains the spectrum of all sources contributing to the overall engine noise. Therefore, the first step in creating an acoustic model is to subtract the jet noise (estimated by prediction or by extrapolation from model data) [14]. The acoustic tests are carried out at open spaces. Figure 3 presents the measurement site located in an open space. The measurement station consists of: an engine mounted on a tripod, a turbulence control system (TCS), and a measurement system – a microphone system. To avoid turbulence resulting from air turbulence reflected from the ground, the engine must be mounted at the appropriate height. The TCS is positioned upstream of the engine intake to reduce atmospheric turbulence. The stand itself must also be sufficiently far from acoustic obstacles.

Fig. 3. RR Trent on a test stand no.11 equipped with a TCS system [2]

As the measurements are carried out outdoors, it is important to monitor atmospheric conditions, for example, wind speed and direction, ambient temperature, atmospheric pressure, ground temperature, etc. Test stand no. 11 Rolls Royce is shown in the drawing (Fig. 3), the entire measurement platform has the ability to rotate 360° thanks to the hydraulic drive, which enables it to be adjusted according to the blowing wind. The entire measurement system is controlled from the control room and consists of three elements: a system control station – System Control Workstation – for initiating and controlling the noise measurement system and all processes; a weather monitoring computer – displaying current weather conditions, an analysis computer – allowing analysis (viewing or printing) of saved data [2].

The microphone arrangement depends on the type of research being conducted (Fig. 4). For example, the measurement system of the DGEN380 engine has 29 microphones placed on a 20 m long arc, the center of which coincides with the axis central engine. In addition, the right side of the engine was positioned in line with the engine axis foldable – a nine-bar system with a diameter of 2.5 m (6 microphones on each beam) [16].

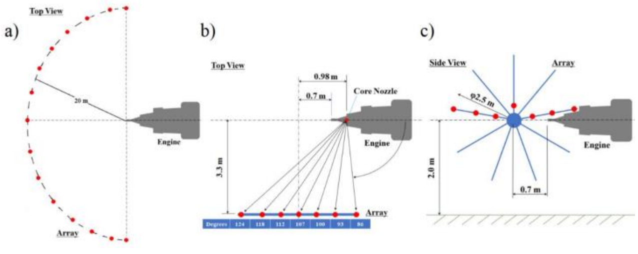

Fig. 4. DGEN 380 test stand. a) top view or microphone array form in arc, b) directional noise measurement, c) ray form measurement [8]

## 2. Micro gas turbine noise

### 2.1. Test engine

The research object was the GTM-120 micro-scale gas turbine engine. It is a single-spool gas turbine engine. The design is a 1R-1 – single-stage radial compressor, and single-stage axial turbine (Fig. 5). This layout is relevant to the early designs like Turbomecca Marbore (J-69) engines. This type of internal structure is still used by APUs (Auxiliary Power Units) or in simplified engines dedicated to drones.

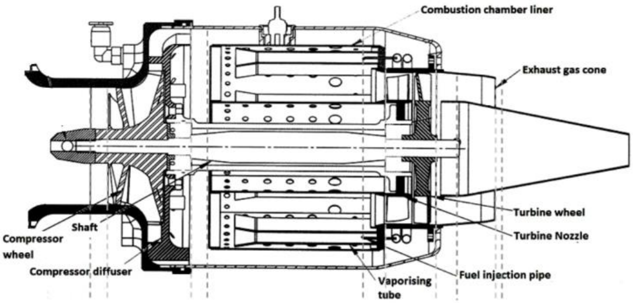

Fig. 5. GTM-120 turbojet engine [3]

Due to this design's affordable price, engines of this class are used in research university test facilities [4, 5, 13]. The total length of the engine is 265mm and the maximum diameter is 110 mm. This engine operates on Jet-A1 kerosene fuel and is controlled by a provided standard Project ECU control system. The engine rotor rotational speed in operating conditions reaches 32 to 120 thousand rpm from idle to the maximum thrust. Engine parameters at maximum conditions are thrust 12 daN, fuel flow – 440 ml/min. The engine's electric starter was disassembled due to the front of the compressor's interaction with the starter structure (air start configuration).

### 2.2. Test methodology

Experimental tests of the engine acoustic field were performed in an open space (Fig. 6). The reasons for conducting the research using this method were due to the following: lack of availability of the anechoic chamber, and to incorporate of safety measures aimed at protecting the health of the people conducting the research. A micro-class jet engine with an airflow of 0.2 kg/s is able to fill a room, with a volume of 25 $m^2$, with exhaust gases in less than 146 seconds, which is a serious health hazard. When performing acoustic tests in an open space, one should remember about certain limitations resulting from conducting this type of research. The measurement station itself should be at least 3.5 meters away from any reflective surfaces that could disturb the measurements by generating reflections of acoustic waves. Another factor worth considering is the level of the general acoustic background noise at the place of testing. If it's possible, the background sound pressure level should be measured with the sound source turned off. If the background noise is 10 dB more or less than the noise level produced by the source, the error from neglecting the background noise is less than 0.5 dB.

If the background noise is 20 dB more or less than the noise level of the measured source, the measurement error is less than 0.1 dB. In this case, the background noise level will have a negligible impact on the measurements. If the difference between the background noise level and the source noise level is less than 3 dB, accurate measurement of the noise level at the source is very difficult. A solution to perform more accurate measurements in the case of high background noise levels may be to move the microphone closer to the measured sound source [10]. Increasing the difference between the measured noise level and the background noise could be difficult due to high exhaust gas temperatures – in the case of measuring noise from the back of the engine.

Fig. 6. GTM-120 turbojet at an open space test area

The research was carried out during the holiday season in an empty car park. The measurement station prepared for the research is shown in the drawing (Fig. 8). The test site was a car park; there were no obstacles in the engine operating zone, the presence of which would significantly affect measurement disturbances. The day was sunny. Ambient conditions during the study were: air temperature of $22^{o}$C, pressure 1018 hPa, and calm conditions 0–1, according to the Beaufort scale.

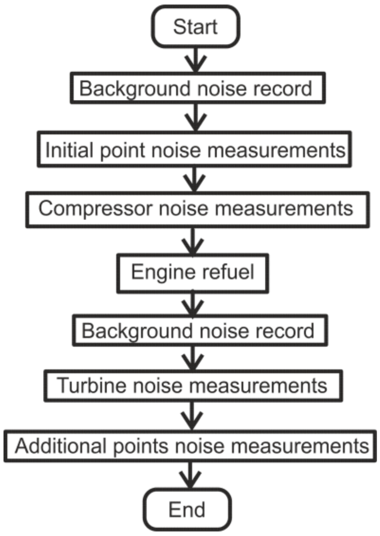

Fig. 7. Noise measurement procedure

The scope of the conducted research was divided into three parts. The first one was to measure the noise levels for specific engine speeds. The next part concerned measuring the acoustic field of the compressor and turbine. The final part provided the opportunity to measure the noise level of omitted points of particular interest that were not covered by previous measurements (Fig. 7).

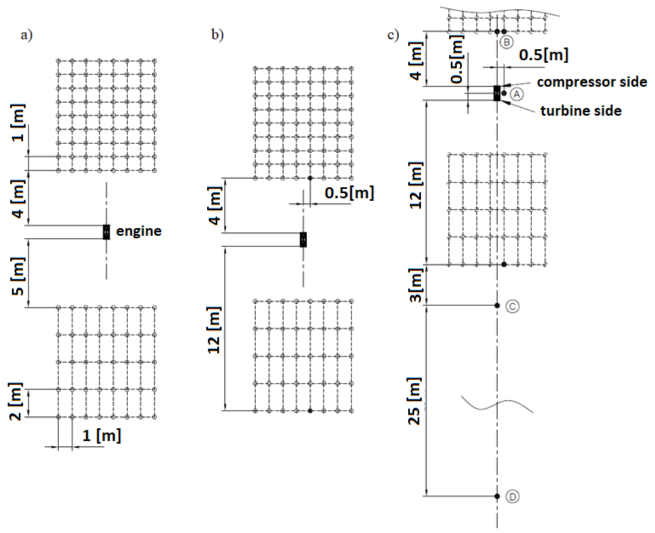

Fig. 8. Test stand configuration a) acoustic field compressor/turbine, b) various rpm configuration, c) far noise configuration

The measurement station for the tested acoustic field of the compressor and turbine is shown in (Fig. 8a). The array of measurement points is located 4 m from the front of the compressor and 5 m from the front of the turbine. To measure the acoustic field of the compressor, 64 points spaced 1m apart were used, and for the turbine, 40 measurement points were used.

Initial engine run "run zero" was used to identify the baseline noise level. Initial point (Fig. 8b) was chosen, they were placed at a point 0.5 m away from the engine axis to avoid interactions with the main part of airflow and for safety reasons. The initial distance was 4m from the front of the compressor, and 12 m from the turbine's front. The *First part of research*: the measurement of the noise level at various rotational speeds was carried out for two different configurations – the setting was different depending on whether the measurement concerned a compressor or a turbine (Fig. 8b) – black dot points. *Second part*: acoustic noise measurements for the compressor and turbine were carried out at a constant rotational speed that was set at 100,000 rpm. Measurements at each point lasted 30 seconds, then the meter was set to the next measurement point; the setting was different depending on whether the measurement concerned a compressor or a turbine. *The third part* was conducted to measure the noise level far away from the engine to identify safe/unsafe conditions. An additional consideration was to measure the noise near the combustor – point A (Fig. 8c).

## 3. Results

### 3.1. Noise measurement in characteristic points

For the analysis to be carried out, it is necessary to verify whether the measured results at selected points (Fig. 8c) are reliable; there is also a horizontal measurement of the acoustic background. This measurement was performed with the device's turned and non-operational engine. The average value measured was 51 dBC. This value is shown in a collective graph of the examined points, denoted by (T) with the marked average standard deviation (Fig. 9). The average measured value of the noise level for the combustion chamber (A) was 109 dBC. The average noise level measured at the engine axis for the compressor (B) was 98 dBC. For the turbine, the average measured noise level at point (C) was 77 dBC, while at point (D) 70 dBC. The collected data is presented in Fig. 9. The average standard deviation for the results of the tested measurement points was also considered. The noise level for the combustion chamber and compressor are significantly higher than the background noise level – greater than 20 dBC, hence the negligible measurement error (less than 0.1 dBC [5]). Turbine noise levels in the engine axis are closer to the background noise level, but they can still be considered reliable – a difference of 10 dBC introduces an error of approximately 0.5 dBC [5, 2].

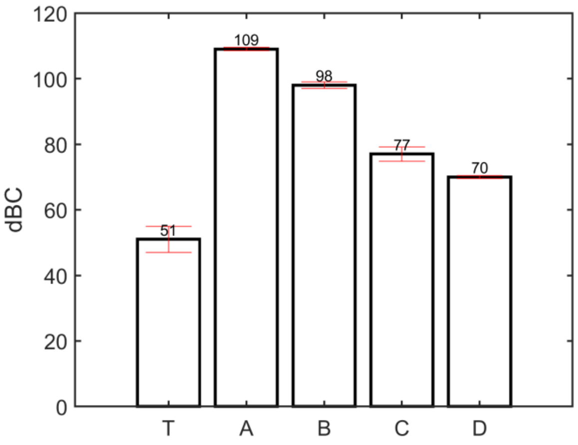

Fig. 9. GTM-120 engine noise levels at selected points.

### 3.2. Noise level measurement for variable rotational speeds

Figure 10 presents the compressor noise level in relation to the various rotational speeds along with the average standard deviation. It was observed that as the rotational speed increases, the sound pressure (noise) level increases. This phenomenon is noticed in both the compressor and the turbine. That is a qualitative indicator that research was conducted the proper way.

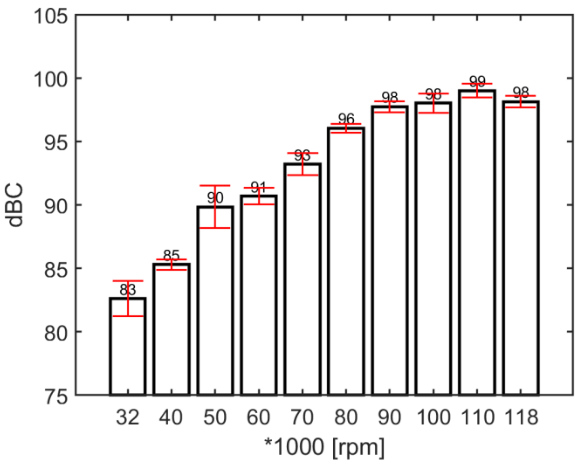

Fig. 10. GTM-120 engine compressor noise levels at various rotational speeds

Considering turbine measurements (Fig. 11), there is a noticeable difference in the noise level in comparison to the compressor side of the engine. The noise from the turbine is noticeably lower. This is largely due to the significant difference in the distance of the measurement point from the sound source (Fig. 8). During the test we followed the rule: safety first.

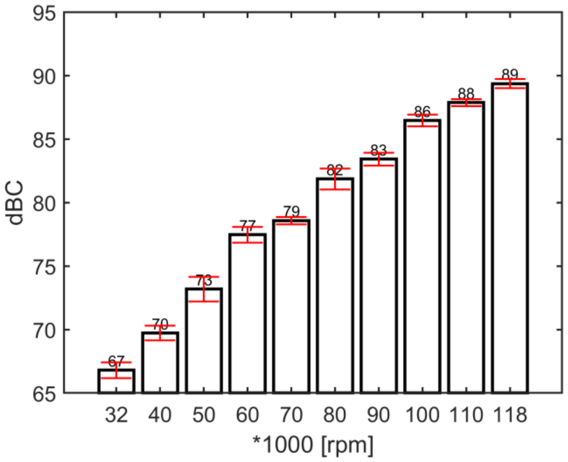

Fig. 11. GTM-120 engine turbine noise levels at various rotational speeds

### 3.3. Measurement of the noise level of the compressor and turbine acoustic field

To identify the acoustic array, we need to follow the numbering rule of selected points – Fig. 12. Measurement starts from the left-hand side and progresses by adding the next measurement (column direction) to the right-hand side. After completing the column, an addition matrix row is considered.

The difference in adding a row to the noise measurement matrix is the direction of measurement. For the compressor, measurements are taken while moving away from the noise source. For the turbine, measurements are taken while moving towards the noise source. If there is any risk, it is possible to stop the measurement procedure.

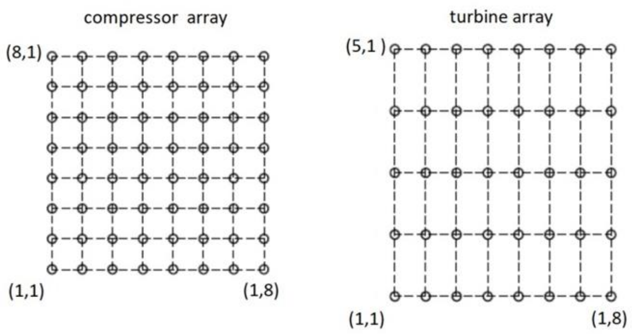

Fig. 12. Acoustics array for compressor & turbine noise measurements

Figure 13 presents the average measured noise level for compressor – specific points. According to the measurement procedure, it can be concluded that the conditions of the study were sufficiently stable, and the measurement errors obtained did not affect the results significantly. The highest value was measured at the axis closest to the front of the compressor, and its value was 97 dBC. The lowest value was recorded at the point furthest from the front of the compressor; its value was 87 dBC. The difference between the average highest measured value and the lowest is 10 dBC.

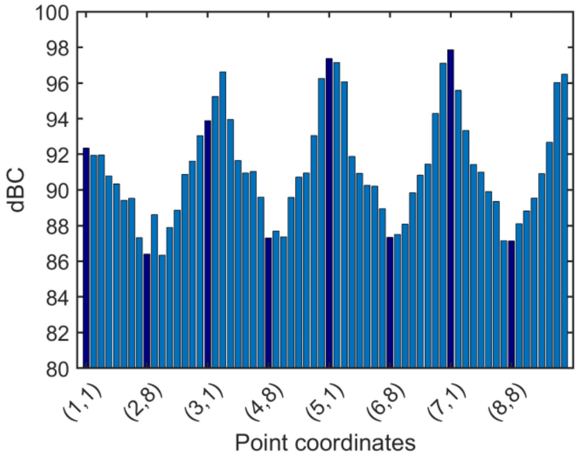

Fig. 13. Results for acoustics array for compressor noise measurements

The presented acoustic flow field (Fig. 14) informs us that the area with the highest values is not symmetrically distributed relative to the engine axis (on the graph between points 4 and 5). This phenomenon reveals the non-axial angle of air inflow into the rotor, which is the nature of the centrifugal compressor's design. GTM-120 engines were based on Garret T04B – series 409179 – compressor wheels. Additional disturbances in the measured acoustic field may be caused by changing environmental conditions resulting from the place where the test was carried out – the open space. The lowest measured value is greater than the acoustic background by 26 dBC, thus the measurement error can be considered negligible, and the results are reliable; in short, the acoustic background does not significantly affect the result values.

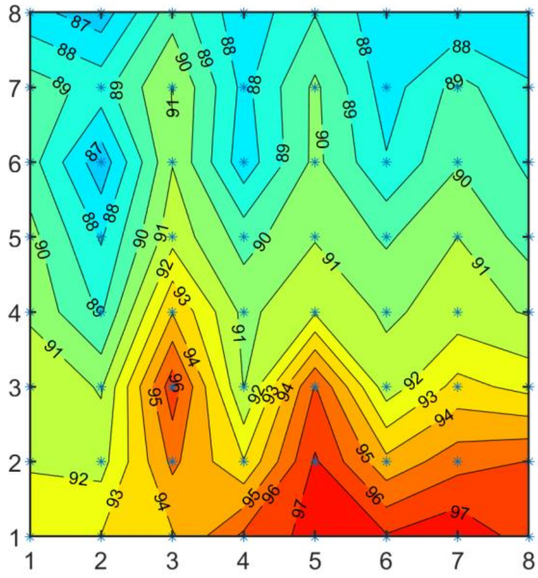

Fig. 14. Results of the acoustics flow field for compressor noise measurements (dBC)

The turbine noise measurements (Fig. 15), similar to the results of the compressor (Fig. 13), present average measured noise levels at the individual measurement points. The measured noise levels are noticeably lower than in the case of measurements of the compressor. It should be remembered that the measurement field was moved away from the noise source (turbine side) by one meter when compared to the measurements carried out for the compressor. The highest measured value for the turbine field was 92 dBC. The smallest measured value was 84 dBC. The acoustic background did not significantly affect the results.

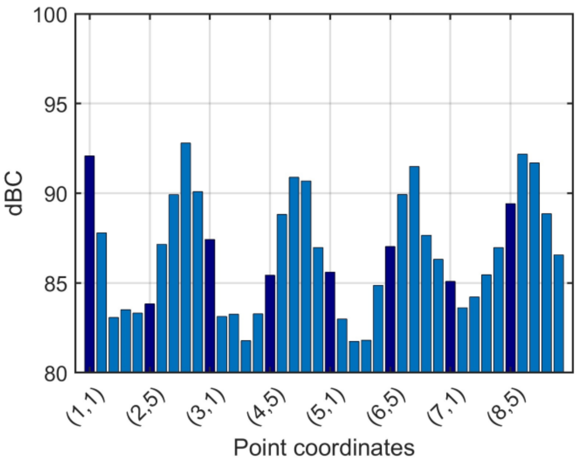

Fig. 15. Results for acoustics array for turbine noise measurements

It was identified that the character of the acoustic field for the turbine is not similar to the appearance of the compressor acoustic field. The main reason is the different characteristics of sound formation at the inlet and outlet of the engine.

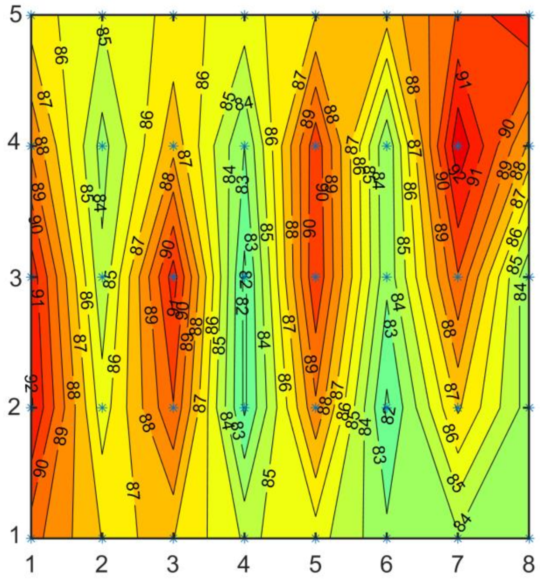

Fig. 16. Results of the acoustics flow field for turbine noise measurements (dBC)

The noise referred to the turbine side in comparison to the internal noise – machine noise, also includes the noise referred to as external that results from the turbulent flow and mixing of exhaust gases with the atmosphere. As in the case of a compressor, the appearance of the acoustic field is influenced by the non-axial turbine geometry and the strong effect of turbine stator-rotor interactions. The final effect is magnified by the elements (three) that hold the central body of the jet pipe cone. This results in the "silent bands" that can be observed in Fig. 16. The turbine flow field corresponds to the result obtained by Lee et al. [9], where the flow field is also asymmetric without rotor stator interaction due to test model configurations. The main difference between the acoustic field of the compressor and the turbine would be the result of a design configuration. The compressor is designed using the rotor-stator configuration and the turbine follows the stator-rotor scheme. The compressor acoustic field is dominated by reflections between the compressor wheel and compressor case. The turbine acoustic field is dominated by the stator-rotor interaction and jet pipe interaction. That phenomenon is consistent with the results published by Tanaka [15]. They correspond to the theory of turbomachinery according to the relative Mach number at the compressor inlet.

## 4. Summary

Knowing the basic processes of noise generation in a jet engine, we can expect that the main source of noise will be the engine exhaust. The noise level from the engine exhaust consists of all the turbomachine noises, including noise from the combustion chamber resulting from violent combustion processes, and the jet noise resulting from the turbulent mixing of exhaust gases with the atmosphere. The literature states that sound levels for jet engines are 150 dB [6]. Considering the size of the tested engine, we can expect lower sound levels, which are related to low-pressure ratios and a thermodynamically inefficient design.

Obtained results of the analysis that characterize noise generation in micro-class turbine engines allow one to move away from the hypotheses. Based on facts – experimental data – the noise level in the vicinity of the running engine was determined and visualized (Fig. 13, 15). As expected, the results obtained are significantly lower than those in the literature – representing sound levels for full-size engines. The obtained measurements can be considered reliable. The lowest difference between the obtained measurements and the acoustic background was around 10 dBC, the measurement error in this worst-case scenario remains at the level of approximately 0.5 dBC, which is considered negligible. Analysis of the acoustic field allows for determining the tendency of noise propagation for a jet engine, thus determining safety zones. After analyzing the results obtained by the acoustic field (Fig. 14, 16), there is the conclusion that working with micro gas turbines could be dangerous, or at least unpleasant [7]. The average noise level obtained for the compressor is from 87 dBC to 97 dbC; for the turbine, it is from 84 dBC to 92 dBC. In both cases, the measured noise level is harmful to humans. Noise above 70 dBC, over a prolonged period of time, may start to damage your hearing. Loud noises above 120 dBC can cause immediate harm to your ears according to the Centers for Disease and Control Prevention. The highest sound level was obtained near the combustion chamber, which was also the point closest to the engine. The impact of the received noise level of 109 dBC is already very harmful and may cause severe disruption of the nervous system and permanent hearing damage. Other sources categorize “noise pollution” and noise above 105 dB as “traumatic”, the range between 90 to 105 dB as “threatening”, and noise below 80 dB as safe [12]. Therefore, any operator should use appropriate protective measures to avoid unpleasant effects resulting from a long-term stay in the risk zone. According to Fig. 8, the minimum safe distances to stay in the area of a micro class engine without protective measures should be no less than 12 m from the compressor side and at least 15 m from the turbine side. Staying within 5 meters of the engine will damage the hearing of an operator. Final recommendation for future research is to measure noise in order to determine its direction relative to the engine. Inside, near the combustor, install a muffler to suppress the sound level, and install additional protective mufflers when long-term engine operation is considered. It is also worth considering vibration measurement to allow the identification of machine noise and the diagnostic of the engine. As a warning for gas turbine operators, an author diagram of hearing loss is presented.

Working in a gas turbine environment as a maintenance engineer and scientist for twenty years has caused hearing loss of about 29 % in the left ear and 8% in the right ear (Fig. 17). Final recommendation is that, even for micro turbo machinery, a properly silenced test facility is essential. According to scientific reports, approximately 33% of working-age adults with a history of occupational noise exposure have audiometric evidence of noise-induced hearing damage, and 16% of noise-exposed workers have material hearing impairment [16]. Obtained results lead to the final conclusion that any type of micro gas turbine engine should be obligatorily tested at a prepared facility that allows one to separate operators from the noise source.

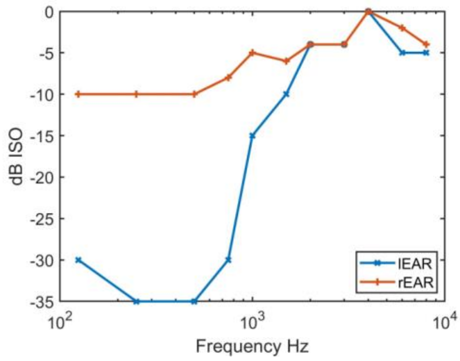

Fig. 17. Author audiometry results provided by Medyk medical center

## Nomenclature

| | |
|---|---|
| APU | auxiliary power units |
| dB | decibels |
| dBC | decibels in C scale |
| MGT | micro gas turbine |
| TCS | turbulence control system |

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