TURBULENCE CONTROL SCREEN IMPACT ON TURBOFAN NOISE SPECTRA IN FAR SOUND FIELD

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As a result of turbofan noise investigations in static conditions, in wind tunnels and in flight conditions, it was determined that during tests in static conditions the fan noise levels of the turbofan were overestimated in comparison with the tests in flight conditions. The point is that the surface layer air is usually highly turbulized and contains vortices of different sizes. In starting conditions the engine sucks the air from all over the front hemisphere, whereas during the aircraft progress even at a low speed the engine ingests only the direct air flow. In first case the vortex situation in the whole front hemisphere is represented at the inlet section of fan rotor, in second case – only the vortex situation in the direct air flow. In second case the presence of strong turbulent atmospheric vortices near the engine will be noticeably weaker and the inlet nonuniformity level will be less. Simultaneously during the aircraft progress the airflow along the intake leading edges appears to be better, local flow separations disappear and the flow becomes more uniform. The most effective tool of approximation the test results in static condition to the flight conditions is the utilization of turbulence control screen (TCS), damping and smoothing the airflow at the engine intake in static conditions. The main parameters of TCS, developed in CIAM for experimental investigations of universal propulsion simulator in test facility equipped by the anechoic chamber, are represented. Current work represents the TCS influence on noise spectra, measured in far sound field in the anechoic chamber environment. It was obtained that the TCS have an effect mostly on the fundamental tone levels at fan blade passing frequency.

1. Introduction

Experience in noise measurements of turbofan engine with high bypass ratio carried out in open-air test facility environment showed that noise levels, generated by the turbofan, were noticeably increased in such conditions. Moreover any turbofan engine tested in open-air test facility environment usually demonstrates additional increase in noise levels. It is known that the surface layer air is usually highly turbulized and contains vortices of different sizes. In start conditions engine sucks the air from all over the front hemisphere, whereas during the aircraft progress even at a low speed engine ingests only the direct air flow. It is obvious that in second case the presence of strong turbulent atmospheric vortices near the engine will be noticeably weaker and the inlet nonuniformity level will be less. Simultaneously during the aircraft progress the airflow along the intake leading edges appears to be better, local flow separations disappear and the flow becomes more uniform. Noise increase caused by the inlet nonuniformity growth is the issue of the same nature. When at Runway the aircraft reaches the speed of about 50 km/h the engine noise reduces significantly – sometimes by 5-8 dB. In open-air test facility environment all noise measurements are carried out in
start mode, and so show overestimated values. Accordingly, aircraft noise levels in three certification points are also overestimated.

There are a large number of publications dealing with the problem of the aircraft speed impact on the engine noise\(^1\).\(^2\).\(^3\).

One of experiments conducted at the flying laboratory included noise measurements of turbofan RB211\(^4\). Microphones were installed in the turbofan intake and fan duct and also on the flaps and trailing edge of the wing. Figure 1 represents results of tone noise registration at BPF in static conditions and in flight conditions (at speed of about 350 km/h) in the same power plant operating mode. It is clearly seen that the tone component pulsations observed in static conditions disappear completely in flight conditions and the tone component becomes stable. Essential reduction of absolute noise level was also found. In average this reduction was equal to 5 dB; periodically reaching 15 dB.

![Figure 1. Time realizations of noise level at BPF for full size engine.](image)

Also experiments showed that at all subsonic fan speeds the reduction of noise level at BPF was observed when changing from static to flight conditions. In the region of relative Mach numbers, lower than approximately 0.85, there is a clear dependence between the noise reduction and the boundary layer thickness on the intake wall.

Investigations of aircraft speed impact on the engine noise were also carried out in wind tunnels\(^5\). Turbofan engine JT15D-1 tests in static conditions and in wind tunnel showed the following:

At simulation of flight speed equal to 360 km/h in the wind tunnel the sound power level at BPF in front hemisphere was reduced on the value of 10 dB as compared with experimental results, obtained in static conditions. This sound power reduction turned out to be the result of rotor - turbulence interaction reduction.

At simulation of flight speed at high subsonic circumferential fan speed the interaction between the rotor and circumferential pressure nonuniformity caused by the struts installed downstream the rotor seems to be the main noise source at BPF.

Hence the extensive researchers have discovered that the flow nonuniformity generated by the atmospheric turbulence and vortices, going from the ground surface or elements of test rig structure leads to the significant overestimation of turbofan fan noise in tests in static conditions\(^6\). This additional noise noticeably complicates obtaining reliable information on engine noise emission in flight conditions and frequently exceeds the benefit of noise reduction technologies implemented in turbofan design. That is why special attention was given to turbulence control screen (TCS) design, approaching the test environment to the real flight conditions. TCS became an integral part of technical equipment for open-air test facility for experimental investigations of turbofan and test sells for turbofan fan model testing.

2. **TCS design and test results**

This chapter represents review of the works devoted to TCS design and experimental investigations. Theoretically all TCS have similar design, being somewhat larger in size than wind screens usually applied in wind tunnels for uniforming the flow, but curled-up in spherical shape. The issue of TSC manufacturing as a self-bearing structure of 6 m diameter for full size engine testing turned out to be very complicated, as this structure should not introduce its own turbulence sources and
may double its own weight at humidity absorption. Nevertheless now most turbofan manufacturers consider turbulence control screen as mandatory test equipment, which should be carefully calibrated in order to take into account any acoustic transition loss, usually not exceeding 1 dB.

As an example let us consider one of the earliest works\(^7\), describing the turbulence control screen (TCS). This TCS reduces the inlet flow nonuniformity and provides an opportunity of obtaining the fan acoustic performances similar to the flight conditions. Generally this paper is devoted to the TCS design, suppressing atmospheric turbulence at the fan inlet.

Tests, conducted in wind tunnel, showed that the optimal design choice for suppressing the longitudinal component of the turbulence is the honeycomb structure with the open-end cells oriented along the flow with the ratio of honeycomb thickness to its transverse size of about 4:1 according to the approximate assessment.

However another correlation (2:1) was chosen as acoustic performances of the construction depends on the honeycomb depth. Such design allows reducing amplitude of distortions by 10 times.

The following parameters of the hemispherical honeycomb screen were chosen: the honeycomb transverse size 0.64 sm, in this case the sound field distortions appear only on the frequencies higher 30 kHz; the screen diameter 2.03 m provides an opportunity to reduce distortions by 1 dB at experimental study of fan with the inlet diameter 0.81 m (40% of screen diameter). At chosen screen parameters the maximal air speed inside the honeycomb structure ducts was equal to ~7.5 m/s.

The honeycomb structure consisted of separate ring-shaped sections. The shape of the honeycomb cell in each section changes gradually as the radius decrease. The number of the cells in the section is reducing sharply in the joint of two sections. Owing to design without bearing elements the screen doesn’t generate tonal noise.

Aerodynamic tests of TCS showed, that total pressure loss was negligible and the mechanical parameters of the construction was sufficient for conducting investigations in the whole range of fan mass flow rate.

Acoustic tests of the honeycomb screen showed, that within the frequency range up to 25 kHz acoustic loss, inserted by the honeycomb structure under consideration, were small. The hemispherical honeycomb screen combined with the corresponding intake, simulating velocities flow field in flight conditions, has the wide range of properties necessary for experimental study of fan acoustic performances.

Experimental study of QCGAT engine carried out at NASA open-air test facility with two turbulence control screens and three intakes, differing in leading edge shape, demonstrated, that both TCS have reduced the interaction noise of rotor and inlet flow nonuniformity\(^8\). Acoustic performances of the engine with different turbulence control screens and intakes of different leading edge were obtained. Comparison of numerical and experimental data in far field in terms of tonal and broadband noise was provided. When installing the TCS on the engine without acoustic liner the significant reduction of tonal noise at BPF equal to 5-8 dB all over the front hemisphere was obtained. In experimental studies of engine with the same TCS it was obtained, that tonal noise reduction in the front hemisphere has similar values with and without liners installed in the intake. In the rear hemisphere basic tonal noise reduction was obtained in configuration with liners installed in the engine bypass duct, as a result the TCS efficiency was low. Broadband noise reduction in configuration with TCS turned out to be insignificant and equal to 1-2 dB. Directivity diagrams of tonal and broadband noise were practically identical at testing the engine with air intake of different leading edge shape.

In NASA Lewis Research Center on base of best previous projects the turbulence control screen was developed and tested; its acoustic performances were determined in experimental study of turbofan\(^9\). The main goal of this study was development of relatively inexpensive TCS of light weight with satisfactory acoustic properties, at the same time essentially smaller in size and simpler
in design as compared with large and heavy constructions, used at that time in open-air test facility environment. The final structure has the size of about two fan diameters and is fixed to the intake surface of hood shape. The TCS was assembled from nine triangular sections covered by flexible honeycomb layer of 5 sm (2-inch) thickness with the nominal cell size 0.6 sm (0.25-inch). Each section was pre-shaped and cut off, then the edges were covered by epoxy adhesive and carefully glued to the steel ribs of 0.04 sm (0.015-inch) thickness. Adjacent ribs were welded together by spot welding forming the load-bearing structure. The shape of the TCS surface was chosen on base of prediction so that the honeycomb cells were oriented along the streamlines.

Recent work describes TCS design\textsuperscript{9}. This TCS is installed at the test fan rig. The influence of TCS on inlet fan modes generation has been studied.

3. Turbulence control screen for UPS installed at anechoic chamber

The design of TCS mounted at the inlet of fan model with the diameter 400 mm was based on a prototype described in work\textsuperscript{10}. This TCS uses only honeycomb (without grids and perforated panels) for flow uniforming. Nine stiffening ribs, produced from stainless steel sheets (1 mm in thickness) and welded together, form the framework. Aluminum honeycomb panels, pre-shaped and cut off using a spatial template are placed between these stiffening ribs. Height of these honeycomb blocks is 25 mm, foil thickness - 0.04 mm. The cells have a regular hexagonal shape with 2.5 mm side. The honeycomb block thickness-to-cell diameter ratio is 5.77 and width of stiffening ribs – 50 mm. The honeycomb panels are flush-mounted relatively to the internal edge of stiffening ribs. TCS fastening to load-bearing components of the acoustic chamber is provided by thin struts. The clearance between the TCS and the inlet surface is filled by a soft sealant.

In order to define the TCS shape the velocity field around of the fan model in the design mode for axisymmetrical problem statement was calculated with the account of free jet ejection and external flow boundaries (i.e. acoustic chamber outlines). On the basis of calculated velocity field the lines perpendicular to streamlines as well as flow velocity contours were drawn (Figure 2).

![Figure 2. Mach number contours, lines of velocity vector continuity, streamlines and perpendicular to streamlines surfaces at the UPS inlet.](image)

The best form of TCS surface generating line is the line perpendicular to streamlines because it provides an ideal streamlining of honeycomb cells. If this line coincides with the flow velocity contours, this is the ideal generating line for TCS surface because it also provides a constant pressure drop.

Figure 2 demonstrates, that there are no ideal generating lines in an actual flow field; moreover, lines perpendicular to streamlines but beyond the high velocity area (>12 m/s) are not closed by
the test object cowling. Therefore, the solution was proposed to construct the generating line of TCS surface so that:

- It would be closed by the test object cowling.
- TCS diameter should be less than 3 diameters of the first rotor.
- Deviation of incoming flow angle from the perpendicular to the surface should be <45°.
- Changes in pressure drop along the surface generating line should be <3 Pa.

As a result of several iterations the generating line shape meeting all above-listed requirements was chosen (Figure 3).

A quadrupole air noise source mounted at the nacelle inlet instead of the UPS was used to check acoustic transparency of the TCS. Noise measurements were made with and w/o TCS; the measuring microphones were installed in the far sound field. In total, 24 measuring channels within the segment 10° - 160° relatively to the inlet fan axis were used. Measurements showed that the effect of TCS on a total noise level of the quadrupole noise source was less than 0.5 dB in all directions, except for the segment 80° – 90° where the difference of noise levels was 1.6 dB and 1.8 dB, respectively (Figure 4).

Figures 5 shows narrowband spectra of UPS noise at supersonic mode 95% of nominal speed in the front hemisphere (Fig. 5, a) and in the rear hemisphere (Fig. 5, b). The installation of TCS results in the insignificant tonal noise reduction.

Figures 6 shows narrowband spectra of UPS noise at subsonic mode - 65% of nominal speed. The installation of TCS results in the tonal noise reduction at BPF up to 10 dB in the front hemisphere (Fig. 6, a) and 6 dB in the rear hemisphere (Fig. 6, b).
Figure 4. TCS acoustic transparency.

Figure 5a. Spectra of UPS at 60° for 95% NRS.

Figure 5b. Spectra of UPS at 120° for 95% NRS.

Figure 6a. Spectra of UPS at 60° for 65% NRS.

Figure 6b. Spectra of UPS at 120° for 65% NRS.

Figure 7 shows the influence of TCS installation at the inlet of UPS on tonal noise at BPF in form of noise reduction directivity diagrams. As expected noise tonal components in the front hemisphere were reduced larger than in the rear hemisphere. The tonal noise reduction at BPF reached significant values 12 dB in certain directions.
The difference between 1/3-octave sound power levels containing BPF is up to 12 dB measured with and without TCS; and increases at rotation speed increasing in subsonic modes (Fig. 8). For supersonic rotation speed $L_W$ are similar.

CONCLUSIONS

1. While testing the turbofan in static conditions the fan noise levels turned out to be overestimated in comparison with the same tests in flight conditions by 10 dB due to high turbulence of surface layer air. The most effective tool of additional noise reduction is the utilization of turbulence control screen (TCS), damping and smoothing the airflow at the engine inlet in test bench conditions.

2. To provide the measured UPS noise levels approximate to flight conditions in CIAM test facility with the anechoic chamber the design of turbulence control screen has been developed and the parameters of TCS has been defined. It was revealed, that the TCS under study provides an op-
portunity to simulate the fan flow corresponding to flight conditions. At that the TCS effectively reduces the inlet flow nonuniformity, decreasing the fan tonal noise components by 12 dB. Study of the turbulence control screen acoustic transparency showed that in the operating frequency range acoustic measurement errors caused by the TCS were within the range ±0.5 dB.

**NOMENCLATURE**

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>BPF</td>
<td>Blade Passing Frequency</td>
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<tr>
<td>L(_W)</td>
<td>Sound Power Level</td>
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<td>NRS</td>
<td>Nominal Rotation Speed</td>
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<td>SPL</td>
<td>Sound Pressure Level</td>
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<td>TCS</td>
<td>Turbulence Control Screen</td>
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<td>UPS</td>
<td>Universal Propulsion Simulator</td>
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**REFERENCES**