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NEW ACOUSTIC FACILITY FOR TESTING UNIVERSAL PROPULSION SIMULATORS

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Abstract

The facility for acoustic tests of universal propulsion simulators (UPS) in conditions of anechoic chamber is created in Central Institute of Aviation Motors (Moscow). The facility is designed for testing models of single rotating fans and counter rotating fans with simultaneous measuring acoustic fields in forward and rearward semi-spheres. Design features of the anechoic chamber and its acoustic performance are presented; a fan drive system and systems of acoustic and aerodynamic measurements are described.

INTRODUCTION

The universal propulsion simulators (UPS) are widely used for testing of late. The UPS in essence is a fan model of turbofan in a scale of 1/3..1/5 with nacelle including air intake, outer duct and bypass jet nozzle. Decreased size of the engine simulator allows running such tests in anechoic chambers or wind tunnels [1]. Testing engine simulators at anechoic chambers gives fan noise matrices which further can be used for estimation of turbofan aircraft noise.

Nowadays some aeroengine manufacturers again analyze advantages and shortages of turbofans with ducted bi-rotor counter-rotating fan. Earlier bi-rotor UPS were studied in Germany when performing the CRISP (Counter Rotating Integrated Shrouded Propfan) programme [2, 3]. Herewith the engine simulator had 400-mm diameter and its rotors were counter rotated by differential reduction gear with similar design tip speeds of about 227 m/s. Bi-rotor UPS of 320 and 1,000 mm diameter were manufactured and tested by the CRISP programme. However the CRISP programme was closed sooner than the exhausted answers on the question formulated had been received.

ANECHOIC CHAMBER DESING AND PARAMETERS

The anechoic chamber of the C-3A rig (Fig.1) is a rectangular premise of 1150-m^3 volume with the following linear dimensions: height -5.0 m, length – 15.6 m, width – 14.7 m. It is located outside of the main building with other test facilities. The drive gas turbines are mounted on foundations free of ties with the chamber foundations and that provides for its vibro-isolation.

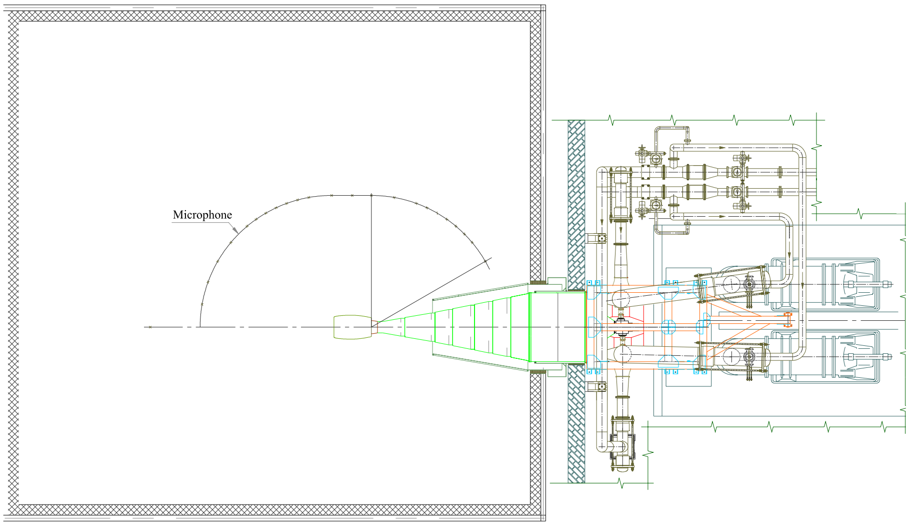

Figure 1 – C-3A test facility anechoic chamber

The chamber structure has a metal frame coated outside and inside by steel galvanized profiled plating. The inner chamber surface is laded with multilayer structures consisting of heat and soundproof panels and frames with sound absorbing material.

A scheme of chamber cut section is shown in Fig.2. As heat and soundproof material 40-mm thick soft basalt slabs and 50-mm basalt mats made on the base of basalt superthin fibers of thickness not more than two microns and placed in glass cloth bags were used. The material was filled in metal panels and closed by perforated plate (perforation extent 40%) looking inside the chamber. Then there were sheets of semihard «vinipor» fixed in special frames located at 50-mm distance from heat-soundproof panels. That air cavity additionally improves coating soundproof properties. As a result the chamber inner surface turned to be clad by sheets of semihard «vinipor» draped with layer of synthetic acoustically transparent “lutroseal” material. «vinipor» plates cover walls, ceiling and chamber floor.

The «vinipor» is material of white or yellow colour with smallpore structure. It is more ignitionproof than poroplast poliuretane elastic and at burning does not emit substances harmful for human health. “Vinipor” density is ρ=120 kg/m^3. «Vinipor» selection as lining material for inner chamber surface is explained by its good sound absorbing properties. Selection of sheet rather than wedge lining is due to high frequency of the tested noise sources (turbofan simulators) which generate main part of acoustic energy at frequencies above 500 Hz.

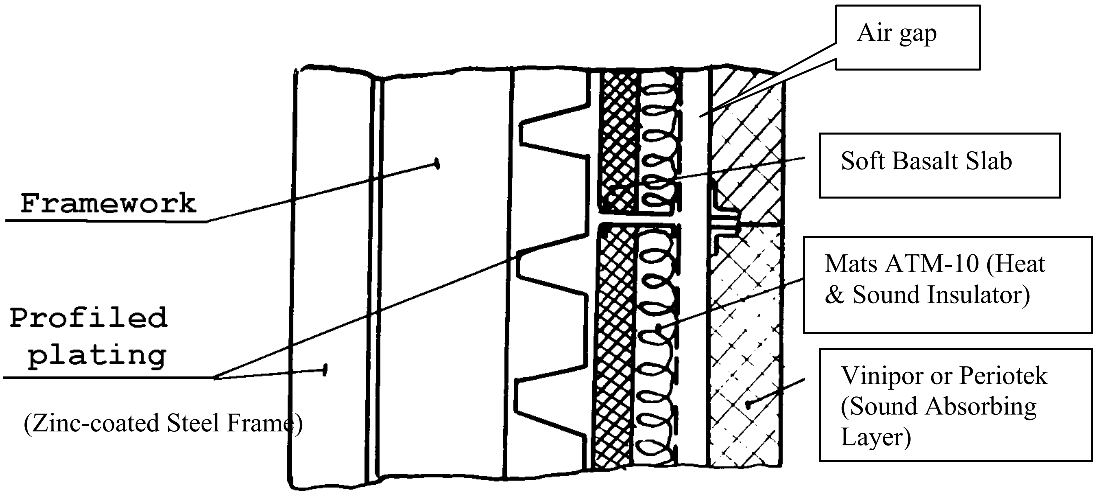

Figure 2 – Anechoic chamber wall design

Acoustic «vinipor» performance was defined at interferometers (Kundt’s tubes) of 30 and 100 mm diameter giving sound absorption characteristics of material in frequency ranges of 700…6700 Hz and 200…2000 Hz correspondingly. It was stated that in an operating frequency range of the C-3A test facility acoustic chamber (>500 Hz) the «vinipor» absorption coefficient at a sound level of 120 dB exceeded 0.8.

Clearly the absorption coefficient of multilayer wall design is significantly higher than sound absorbing material single layer (≥ 0.95).

Fig.3 presents a cross-section of the tested turbofan bi-rotor fan in the UPS system. Maximum fan rotation frequency makes up 13,000 rpm at 2.5 MWt each shaft max power.

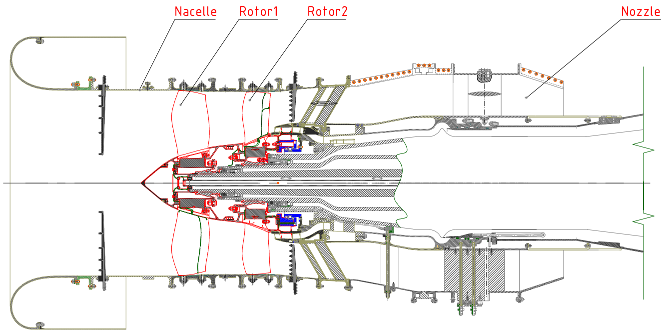

Figure 3 – UPS cross-section

The nacelle casing comprises cylindrical envelopes with flanges. The envelopes are connected by flanges and fixed by bolts. Nacelle casings configurations are defined in compliance with the test programme. For fan aerodynamic tests, i.e. in the aerodynamic configuration the annulus outlet is equipped with a vane throttle and casings with hard smooth walls. In this configuration the nacelle is leaned against the cantilever casing through vane struts located behind Rotor 2 and fan bypass throttle.

For acoustic tests, i.e. in acoustic configuration the annulus outlet is equipped with replaceable nozzles and the casings – with sound absorbing liners and rings with sensors for modal analysis. In acoustic configuration the nacelle is leaned against the cantilever casing through fan vane struts.

Air sucked by the tested fan enters the anechoic chamber through an opening in the floor covering the whole chamber width and serving for placement of a sucking unit and air filter. To make intake air flow more uniform a turbulence control structure (TCS) was designed and manufactured. The TCS is installed in front of the fan and to lower air ejection great part of exhaust jet in the chamber is sucked through the conic surface of shaft drive which is overblown by this jet (Fig.4).


Figure 4 – Conical shaft drive (left), TCS (right)

A mathematical model was developed and analysis was performed for numerical modeling 3D viscous flows in the acoustic chamber. Analysis of the calculated flow speeds, streamlines and total parameters distributions has shown that due to vortex flows air with increased values of P_0, T_0 in exhaust jet can enter the fan inlet and influence upon test results because both in front of and behind the fan large-scale vortices are observed. However, if air is sucked from the chamber in quantity not more than 1.5-fold max air rate through the fan vortices intensity turns out to be not too significant, flow speeds in them are not higher 3..5 m/s and outlet vortices do not enter the fan inlet. The greater total air rate, the greater vortices number and their speeds which results in a rise of flow turbulence level and chamber energy losses. The lower total air rate down to values close to the rate value through the fan, the greater sizes of vortices in the rearward semisphere and they reach the fan inlet. Thus, it has been shown that the selected speed of flow around the tested model is optimum.

Certification of the anechoic chamber included definition of sound field nonuniformity, assessment of max allowable sizes of tested machines which noise performance can be measured in the chamber with allowable accuracy, as well as determination of background noise.

Acoustic field nonuniformity in the anechoic chamber was measured by three sound sources: pattern source of broadband noise presented by a fan with “squirrel type" rotor driven by electric motor, high frequency quadruple jet sound source and standard electrodynamic noise unit OmniPower by B&K.

Field uniformity in the chamber was measured for white and pink noise and also for a harmonic signal. Fig.5 displays an abatement of sound pressure level at a distance from the pink noise source. Red straight line characterizes an ideal free sound field. It is shown that the actual field is very close to the ideal.

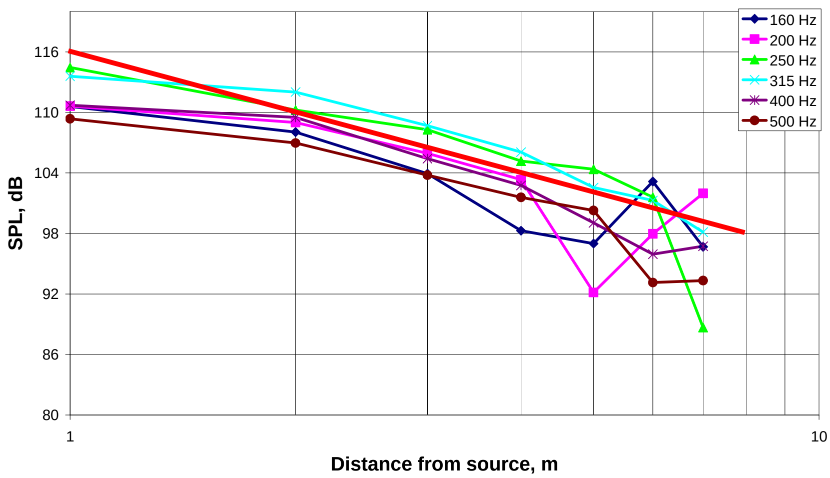

Figure 5 – Verification ~1/R^2

Nonuniformity of acoustic field in various points of chamber inner volume is different. It increases when moving near to anechoic chamber inner surfaces, i.e. with increase of reflected wave amplitude. As far as at different radiation directions noise reaches the inner chamber surfaces at different distances from the source, nonuniformity of acoustic field depends on direction. Besides, absorption coefficient of chamber coating depends on frequency; therefore acoustic field nonuniformity is a function of frequency and increases with its decrease. With the aim to compensate acoustic field deviations inside the chamber from the ideal it is reasonable to use a corrections matrix defined in the process of preliminary studies.

Thus, in general, it was shown that large sizes of the anechoic chamber and perfect sound absorbing properties of multilayer «vinipor» coating surrounding the chamber ensured rather high uniformity of acoustic field in the whole measurement area up to R=7 m and f > 250 Hz.

Background noise in the C-3A test facility anechoic chamber are external noise sources in a space surrounding the chamber (in particular, exhaust shafts of other rigs), C-3A rig drive noise. Note, that model fans are rather high frequency noise sources, though highest levels of penetrating background noise are expected in an area of low frequencies for high frequency noises not so good penetrate through buildings and premises barriers. Besides, there are no powerful high frequency sources of foreign noise near the C-3A rig.

The greatest total background level in the chamber was recorded at operation of neighbor engine rig and was equal to 86.5 dB. In other cases the total background noise varied within 65…75-dB limits and main part of sound energy focused in a frequency range below 200 Hz. Thus, in general, interference level in the chamber makes up a value much lower than an expected noise of model fans tested in it.

Regarding max sizes of tested machines, assessment showed that for fans of diameter up to 0.7 m for which the C-3A rig is specifically designed for a far sound field could be with confidence considered completely formed starting from R=1.5 m at all the frequency measurement range higher than 250 Hz.

As soon as testing 0.7-m diameter model fans are rather common business, there are practically no questions about their aerodynamic modeling. Regarding acoustic modeling, in compliance with the ICAO Standard aircraft and aeroengine noise is measured in a frequency range of 50…10,000 Hz. To maintain aerodynamic similarity at smaller model size its rotor rotation frequency increases. As a result at aerodynamically similar modes the UPS operation frequency range displaces to the side of high frequencies and reaches deep ultrasound. Therefore UPS testing should be performed by means of high frequency units and data processing should take into account increased absorption in air at ultrasonic frequency range reducing the measurement data to standard atmospheric conditions. Remind, that sound absorption in air is a function of mainly temperature and air humidity [4].

The acoustic measurement system in far acoustic field includes 24 microphones located in an arc of 5...7 m diameter from 10 up to 160°. Each measuring channel comprises microphone 4939 (1/4 inch diameter), preamplifier 2670, cable AO0416

(1x30 m length) and four-channel amplifier 2690 (all B&K components). All measuring channels are connected to multichannel digital analyzer by MERA company integrated with PC Pentium-IV. Operating frequency range is in the range from 10 Hz to 80,000 Hz.

The hardware set allows checking in real time results of total three-octave analysis of machine noise along all 24 channels in a measured frequency range.

Besides, the rig is equipped to measure air rate through the fan, pressure ratio in bypass and core, flow fields in fan, unsteady pressure fields in flow, fan vanes and casing, as well as vane vibrations and radial clearance. Additionally measurement of modal composition of acoustic field in fan annulus is stipulated.

SUMMARY

The facility for acoustic testing universal propulsion systems (UPS) of diameter up to 0.7 m in conditions of an anechoic chamber of 5.0*15.6*14.7 m is developed in Central Institute of Aviation Motors (Moscow) and described. The anechoic chamber is covered inside by multilayer structures made of heat and sound absorbing panels and frames with sound absorbing material.

The rig is designed for testing models of single rotating fans and counter rotating fans with simultaneous measurement if acoustic fields in forward and rearward semispheres. Fan rotor max rotation frequency makes up 13,000 rpm at each shaft max power 2.5 MWt.

The rig acquisition system allows checking in real time results of complete three-octave analysis of machine noise on all 24 channels in a measurement frequency range of 10…80,000 Hz.

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