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DESIGNING OF RRJ-95NEW-100 AIRCRAFT WITH REGARD TO CABIN NOISE REQUIREMENTS

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***Abstract**: The work is devoted to the problem of designing aircraft according to the specified parameters of acoustic comfort of passengers and crew members. The initial data for the design of the aircraft are presented. The concept of acoustic design of the RRJ-95NEW-100 aircraft based on the RRJ-95 prototype aircraft is considered. The issues of verification and validation of the calculation software used in the development of "digital twins" (acoustic simulation models) are considered, the main methods of visualization of the sound field in the aircraft cabin are presented.*

***Keywords:** acoustic designing, civil aircraft, cabin noise, "digital twin", acoustic simulation model, RRJ-95-NEW-100.*

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1. INTRODUCTION

Currently, providing increased acoustic comfort is one of the priority tasks of aircraft construction companies. Providing the concept of aircraft acoustic design, i.e. according to the acoustic comfort parameters set by the Customer, is an important task, the successful solution of which ensures the competitiveness of aircraft, especially in the business jet segment [1, 2].

The importance of this topic is confirmed by the currently being developed national standard of the Russian Federation "Requirements for cabin acoustic design of transport aircraft", which will reflect the main research and development work (R&D) within the life cycle, the implementation of which is necessary to ensure the concept of aircraft acoustic design.

The aim of the work is to form the concept of RRJ-95 NEW-100 acoustic design. The features of the concept under consideration are related to the fact that the aircraft is designed on the basis of the successfully operated RRJ-95 aircraft, subject to maximum import substitution of components and systems, as well as taking into account more stringent requirements for acoustic comfort parameters of passengers and crew members.

2. ABOUT THE PROBLEM OF AIRCRAFT ACOUSTIC DESIGN

As the initial data for the acoustic design of the aircraft, we note the following normative documents:

- GOST 20296-2014 (with addition) [2], according to which noise levels in aircraft cabins are normalized. And also the requirements from the Customers of the aircraft are formed.
- Certification specifications and acceptable means of compliance for large aeroplanes paragraph (CS-25) [4] 25.771 (e), Vibration and noise characteristics of cockpit equipment may not interfere with safe operation of the aeroplane.
- Within the framework of the problem of cockpit noise, ISO 9921:2003 [5] formulates an objective criterion for evaluating the quality of recording audio information on the non-directional microphone of the solid-state cockpit voice recorder (SSCVR). Such an objective criterion is the Speech transmission index (STI). The speech intelligibility score "excellent" is provided when STI>0.75. In addition to background noise in the area where the non-directional microphone is located, the reverberation time significantly affects the speech transmission index, which in turn depends on the geometry of the cockpit and the sound-absorbing properties of the interior.
- Acoustic design of a modern civil aircraft in the Russian Federation should be carried out in accordance with GOST R 58849-2020 [6], taking into account the following criteria. The created aeronautical engineering must meet the requirements of the Customer, the requirements for airworthiness and environmental protection from the effects of aviation and ensure the possibility of its effective and safe use. When creating aeronautical engineering, it is necessary to be guided by modern principles of its design and development on the basis of advanced scientific and technical reserve.

When designing aircraft salons with a VIP-interior, the initial data is data on sound pressure levels in the salons of operated and promising business jets. At the same time, the Customer of the business version of the aircraft can independently formulate the required parameters of acoustic comfort in various areas of the cabin. The design solution of this problem is a separate area of work in the aircraft design.

The calculation mode for aircraft designing taking into account the requirements for cabin noise is the cruise straight-line flight mode, which normalizes the noise levels in the aircraft cabin, and for which the placement of acoustic materials in the on-board structure is optimized.

Acoustic materials in the framework of this work are understood as heat-and sound-insulating, sound-absorbing, vibro--absorbing and vibro-insulating materials, metamaterials [7], as well as materials that implement the principles of active noise and vibration suppression used in the aircraft design to ensure the required parameters of acoustic comfort [8].

The content of R&D complex when performing acoustic design of an aircraft depends on the ratio between noise sources in different control sections along the length of the aircraft cabin.

For aircraft with a classical configuration of the power plant – two turbofan engines, located on pylons under the wing, the main noise sources in the cabin are:

- field of pressure pulsations on the fuselage surface (turbulent boundary layer) [9, 10],
- air conditioning system (ACS) [11, 12],
- vibration effect of the power plant (structural-borne noise) [13],
- acoustic loads on the fuselage surface (jet noise [14] and fan noise [15]), etc.

The aircraft developer does not design the aircraft systems, but formulates requirements for system Suppliers and ensures a rational layout of noisy units on the aircraft.

For the power plant (PP), the main problem is community noise, i.e. ensuring the sound pressure levels required for successful certification of the aircraft as a whole in the EPNdB metric in the far field in the sum of three control certification points. The problem of cabin noise is secondary and consists in obtaining data on the sound field structure of engines on the surface of the fuselage, taking into account the use of noise--muffling devices and the real configuration of PP on the aircraft for further modeling of the sound field in the cabin from this source.

3. THE DESIGN CONCEPT OF RRJ-95NEW-100 TAKING INTO ACCOUNT THE REQUIREMENTS FOR CABIN NOISE

The general concept of acoustic design of RRJ-95 NEW-100 aircraft is shown in Fig 1. The list of necessary R&D is formulated in this case on the basis of a in-flight experiment on identification, localization and ranking by intensity of the main noise sources in the cabin of RRJ-95 prototype aircraft [16, 17].

The overall sound field in the RRJ-95 cabin is dominated by the turbulent boundary layer noise and air conditioning system noise, the ratio between which varies along the length of the cabin. The ACS noise can dominate in different areas of the passenger cabin. The main units of the ACS that generate noise include exhaust valves, an air cooling unit, pressure and exhaust fans, recirculation fans, ejectors, air ducts and other elements that supply air to the passenger cabin. If we evaluate the contribution of the jet to the overall sound intensity, calculated through the overall sound pressure levels in dBA, then in the tail section of the cabin it does not exceed 1.5 %. The contribution of structural-borne noise from vibrations of the engine fan shaft does not exceed 4 % in the tail section of the cabin and 10% in the wing section.

The initial data for modeling the turbulent boundary layer noise is information about the structure of pressure pulsation fields on the fuselage surface. To calculate the noise from the acoustic impact of the power plant, it is necessary to have data on the sound field structure of the power plant in the conditions of its real configuration on the aircraft.

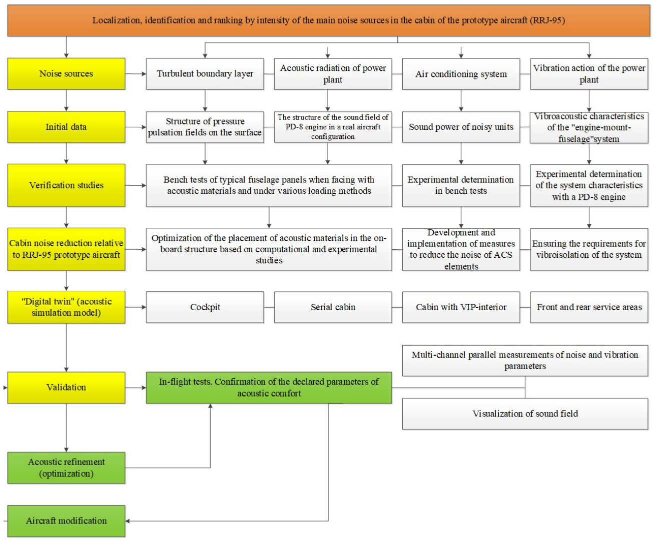


Fig. 1: General strategy of RRJ-95 NEW-100 acoustic design

In order to verify the simulation software and select acoustic materials for use on the RRJ-95NEW-100, studies of typical curved fuselage panels (side and ceiling) with different types of facing with acoustic materials and different types of loading were performed. In model experiments, the field of pressure pulsations is modeled by vibration loading of the panel under study, and the sound field of the power plant is modeled by a diffuse sound field in the reverberation chamber.

To simulate the structural-borne noise from the vibration effect of a power plant, data on the vibroacoustic characteristics of the "engine-mount-airframe" system are needed. Since the PD-8 engine will be installed on the RRJ-95NEW-100, and the SaM-146 engine is installed on the RRJ-95, a complex of additional studies is needed to ensure vibration isolation in the "engine-mount-airframe" system, which guarantees low levels of structural-borne noise in the aircraft cabin.

To simulate the ACS noise and the optimal placement of noisy units, data on the sound power of the main noise sources are needed. Bench tests to determine the sound power of ACS units are performed in accordance with the requirements of ISO 3745:2012 [18].

A separate place in the problem of ACS noise is occupied by the use of noise reduction technologies, both in the source and on the way of sound propagation to the cabin. Suppliers of ACS elements should provide the concept of acoustic design of the system units [19], including providing, if necessary, the installation of sound-proofing housings and vibration-proofing fasteners of the units, as well as the development and installation of mufflers for exhaust valves. Also, to improve the acoustic characteristics of the cabin, it is possible to install dissipative mufflers in the air supply channels to cabin [20]. This method of reducing the ACS noise is provided for on all business jets of RRJ-95NEW-100.

When developing a "digital twin" (acoustic simulation model) of RRJ-95NEW-100, the cockpit, the passenger cabin in serial and VIP configurations, as well as the front and rear service areas are considered separately. At the same time, the methods used for numerical modeling of interior noise are limited by the frequency range and to cover the problem range of the aircraft cabin under study, it is necessary to develop computational models using different numerical methods. For RRJ-95NEW-100 aircraft, the expected problematic frequency range corresponds to the range of 1/3-octave frequency bands of 100-4000 Hz [17].

The main calculation methods and the frequency range of their applicability are considered in Fig. 2. This is Finite Element Method (FEM), Boundary Element Method (BEM), Statistical Energy Analysis (SEA), Hybrid Method (FEM-SEA), and Ray Tracing method, etc. Generally, FEM and BEM are adopted for the low-frequency range, FEM-SEA is adopted for middle-frequency range, and SEA and Ray Tracing Method are adopted for high-frequency range.

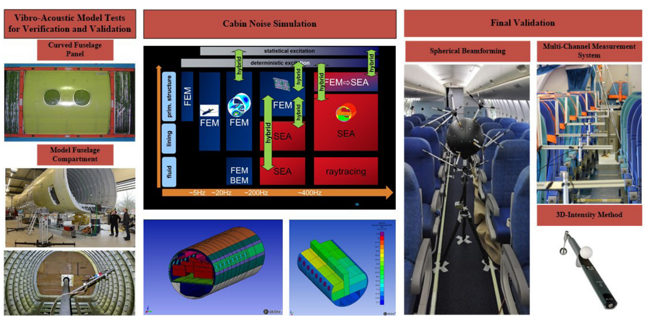


Fig. 2: Verification and validation of the simulation software during the development of the "digital twin" (acoustic simulation model) of the cabin

To verify the simulation software, vibroacoustic tests of typical fuselage panels with different types of facing with acoustic materials are performed, as well as tests of fuselage compartments.

As part of the validation of numerical models [21], it is necessary to perform research using sound field visualization technologies, as well as multi-channel parallel measurements of noise and vibration parameters.

The acoustic refinement (optimization) of the operated aircraft is based on the acoustic simulation model of the cabin. The in-flight experiment is performed before the introduction of design changes in the series to confirm the required level of increase in acoustic comfort.

4. MODERN METHODS OF SOUND FIELD VISUALIZATION IN AIRCRAFT CABINS

Technologies for visualizing sound fields in aircraft cabins are used to solve the following tasks:

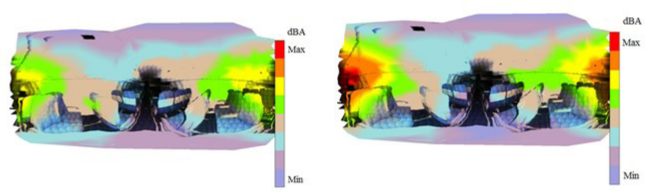
- Localization and ranking by intensity of the main noise sources;
- Determination of sections of the aircraft structure where it is necessary to increase sound insulation or possibly reduce it by reducing the mass of acoustic materials without compromising the acoustic parameters of the cabin;
- Obtaining initial data for verification and validation of calculation methods, especially when developing "digital twines" of the passenger cabin and cockpit;
- Performing acoustic diagnostics of aircraft interiors and searching for the reasons for the difference in the noise characteristics of the cabin of separate aircraft from the acoustic portrait of the series.

Currently, three main technologies are used to visualize the sound field in aircraft cabins:

- Spherical beamforming;
- 3D-intensity method;
- Multi-channel parallel measurements of sound signals with the subsequent construction of noise maps using specially developed algorithms.

When performing acoustic measurements using spherical microphone arrays [22, 23], signal post-processing can be performed by different methods. These are the methods of standard spherical beamforming, acoustic holography, equivalent source and deconvolution method, etc.

As an example, the localization maps of noise sources in the RRJ-95 cabin in 1/3-octave band of 400 Hz with a contrast of 8 dBA for cases of ACS on and off are shown in Fig. 3. The characteristic frequency of operation of the system fans is 380 Hz into the frequency band under consideration, and, as expected, the sources of increased noise in this frequency band are located on the side of the air supply pipelines to the cabin. When the ACS is turned off, the intensity level of this source decreases by 2–3 dBA.



a) ACS off *b) ACS on*

Fig. 3: Localization maps of noise sources in the area of the 14th row of economy class seats for 1/3-octave frequency band of 400 Hz (in dBA)

The 3D-intensity method [24] is a development of the classical method of intensity [25], and in fact consists in scanning the sound field using an acoustic (intensimetric) probe when it moves along the enclosing surface. The acoustic probe of such a system can include from 1 to 4 microphones, depending on the signal post-processing algorithm. If several microphones are included in the acoustic probe, then in this case it becomes possible to build 3D sound intensity maps in vector form. Such maps can help determine the location of noise sources. When using a single microphone as part of an acoustic probe, it is possible to build acoustic maps of only scalar values along the measured surfaces.

As an example, a sound intensity map obtained in a vertical plane (marked in blue on the left side of the figure) parallel to the main axis of the aircraft is shown in Fig. 4. The measurements were performed under static conditions when ACS is operated from an auxiliary power plant.

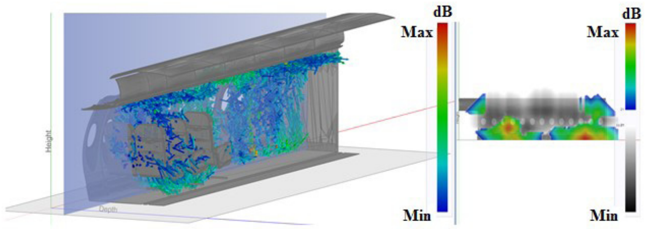


Fig. 4: The sound intensity field in vector form (graph on the left) and the sound intensity map in the vertical plane (graph on the right), marked in blue on the left graph, for the overall radiation in the range of 1/3-octave frequency bands 100-4000 Hz

When building noise maps based on multi-channel parallel measurements in the cabin using microphones distributed along the length of the cabin, the algorithms for visualizing the sound field are based on correlation functions and interpolation of measurement results. An example of building noise maps based on the results of multi-channel measurements on an Airbus A350 is shown in Fig. 5 [26]. Note that in this case, the microphones are located in one plane parallel to the floor plane, and multi-channel measurements of noise signals are performed in accordance with the requirements of ISO 5129:2001 [27].

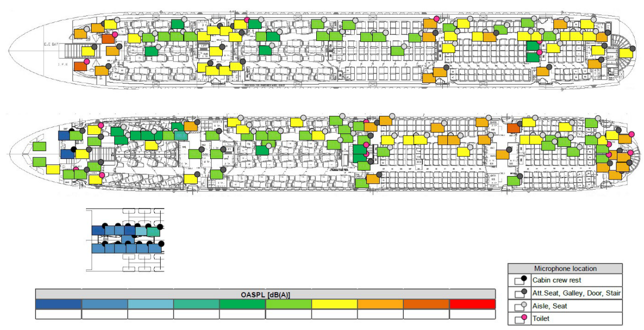


Fig. 5: Example of a noise map based on the results of measurements in the Airbus A350 cabin (the results are presented in dimensionless form) [26]

5. CONCLUSION

The problem of designing civil aircraft taking into account the requirements to cabin noise is considered. The paper presents the concept of acoustic design of the RRJ-95NEW-100. The peculiarity of the concept is that the aircraft is designed on the basis of the successfully operated RRJ-95, taking into account the requirements of import substitution of the main components and systems, as well as the need to ensure promising acoustic comfort requirements. Modern technologies for visualizing the sound field in aircraft cabins and the tasks for which they are used are considered.

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