Assessment of Community Noise for a Medium-Range Airplane with Open-Rotor Engines


Moscow Research Center, Zhukovsky Central Aerohydrodynamic Institute, Moscow, 105005 Russia

Peter the Great St Petersburg Polytechnic University, St Petersburg, 195251 Russia

E-mail: vkopiev@mktsagi.ru

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Abstract—Community noise of a hypothetical medium-range airplane equipped with open-rotor engines is assessed by numerical modeling of the aeroacoustic characteristics of an isolated open rotor with the simplest blade geometry. Various open-rotor configurations are considered at constant thrust, and the lowest-noise configuration is selected. A two-engine medium-range airplane at known thrust of bypass turbofan engines at different segments of the takeoff–landing trajectory is considered, after the replacement of those engines by the open-rotor engines. It is established that a medium-range airplane with two open-rotor engines meets the requirements of Chapter 4 of the ICAO standard with a significant margin. It is shown that airframe noise makes a significant contribution to the total noise of an airplane with open-rotor engines at landing.

Keywords: open rotor, aeroacoustics, modeling, detached eddies, community noise

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INTRODUCTION

An open rotor (a propfan) is a promising powerplant that allows reduction of fuel consumption (and hence CO₂ emissions) by up to 20% in comparison with current turbofan engines [1]. The improved aero-dynamic characteristics of the open rotor (higher flight efficiency than for classical bypass turbofan engines) have repeatedly drawn the attention of airplane manufacturers. A review of non-Russian research on the open rotor may be found in [2]. In Russia, the NK-12 engine (two counterrotating four-blade rotors of diameter around 6 m) was developed in the 1950s and installed in a Tu-114 passenger plane and an An–22 transport plane. The D–27 engine developed in the 1980s (two counterrotating rotors with eight and six blades of diameter 4.5 m) was installed in the An-70 transport plane.

Nevertheless, such engines have not been widely used in civil aviation. One problem is that such engines are very noisy [3]. In turbofan engines, the nacelle duct shields the noise generated by the fan, and it is possible to reduce the noise by acoustic liners or to redirect it appropriately. In contrast, in the open-rotor engines the noise is able to travel freely from its source. That increases noise levels not only within the cabin but community noise as well. The noise in the cabin may be reduced by optimizing the strut and rib configuration [4] and by installing damping and insulating materials [5]. To reduce the low-frequency noise in the cabin typical of an open rotor, one can synchronize the propellers [6] and employ active noise absorption [5].

However, these approaches do not reduce the community noise. For that purpose, the noise may be shielded by the airplane frame — for example, by means of vertical fins [7] or by using a flying-wing design [8]. However, for an open-rotor engine, such shielding requires major redesign of the airplane, and will not be considered here. For an engine of traditional design with open-rotor engines, the main approach to reducing community noise is to optimize the geometry of the open rotor: the number of blades in the front and rear rotors, the blade design, the diameter of the front and rear rotors, the distance between them, and so on.

Computational aeroacoustics enables optimization of the open-rotor geometry so as to considerably reduce the noise level. In the present work, we estimate community noise for an airplane with an optimized open rotor, adopting the simplest family of blades [9].

Note that the noise spectrum of an open rotor is rather complex, with many harmonics. That hinders comparison of the noise spectra for different configurations. For example, modifications that suppress some harmonics may increase the amplitude of others. To overcome these difficulties, we use the EPNdB...
metric in the present work to compare the noise of different configurations. That metric is used in the certification of airplanes in terms of community noise. The influence of the open-rotor geometry on the noise was investigated on the basis of the EPNdB metric in [10], for example, where a semianalytical model was employed, which does not account for the influence of modifications on the engine’s thrust.

In the present work, we compare versions of the open rotor with the same thrust. The aerodynamic characteristics of the open rotor and the nearfield acoustic characteristics are calculated by numerical integration of three-dimensional unsteady gasdynamic equations for a viscous compressible gas, in combination with detached-eddy simulation of the turbulence on the basis of the hybrid RANS–LES method DDES [11, 12]. The farfield noise is calculated by the Ffowcs Williams–Hawkins (FW–H) method using permeable control surfaces. The farfield noise characteristics determined in this way are then recalculated for the flight conditions of the specific airplane in the EPNdB metric.

We consider several modifications of the basic open-rotor configuration (Fig. 1), obtained by changing the number of blades, the distance between the rotors, the blades’ chord width, and the diameter of the rear rotor [9]. Since the calculations demand considerable computing power and time, we consider only nine configurations. For each of these configurations and also the basic configuration, we calculate community noise, at the flyover certification point, for a two-engine medium-range airplane. For the quietest configuration, community noise is estimated for the sum at three control points. The result is compared with ICAO norms.

The organization of this article is as follows. Section 1 briefly describes the method used in numerical calculation of the farfield noise from an open rotor. Section 2 presents the basic geometry of the open rotor, the modifications considered, and the calculation results for the farfield noise. Section 3 describes the method of assessing community noise and presents the results of comparing the noise levels with the ICAO norms. The conclusion section summarizes our findings and outlines proposals for further research.

**1. NUMERICAL METHOD**

In the present work, the aerodynamic and acoustic characteristics of airplane rotors are calculated on the basis of NTS (Numerical Turbulence Simulation) code [16], together with an acoustic FW–H postprocessor for calculating the farfield noise generated by the flow [17]. The codes were carefully validated by comparison of the results of the calculations with experimental data on the aerodynamic and acoustic characteristics of turbulent jets [16–18] and flows over airframe components [19]. This approach may be regarded as reliable and universal.

The computational system from [16, 17] is adapted to enable calculation of the flow in the presence of...