Journal of Engineering and Applied Sciences 12 (Special Issue 9): 8601-8606, 2017
ISSN: 1816-949X

Engine-Propeller Power Plant Aircraft Community Noise Reduction Key Methods

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Abstract: Basic methods of aircraft-type flying vehicle engine-propeller power plant noise reduction were considered including single different-structure-and-arrangement propellers and piston engines. On the basis of a semiempirical model the expressions for blade diameter and number effect evaluation upon propeller noise tone components under thrust constancy condition were proposed. Acoustic tests performed at Moscow Aviation institute airfield on the whole qualitatively proved the obtained ratios. As an example of noise and detectability reduction provision a design-and-experimental estimation of propeller diameter effect upon unmanned aircraft audibility boundaries was performed. Future investigation ways were stated to solve a low-noise power plant design problem for light aircraft and unmanned aerial vehicles.

Key words: Aircraft, propeller noise, engine noise, noise reduction methods, light propeller aircraft, airfield

INTRODUCTION

Engine-propeller power plant aircraft noise reduction problem is determined by ICAO Standard (ICAO., 2011) for limiting community noise levels generated by light propeller aircraft as well as special unmanned engine propeller Power Plant (PP) aircraft community noise requirements.

To essentially reduce piston engine AirCraft (A/C) community noise and detectability level a complex approach is demanded consisting in power plant noise reduction, i.e., noise radiated by a propeller and an Internal Combustion Engine (ICE). Propeller noise reduction is a problem difficult enough. Its solution is based on propeller's geometric, aerodynamic and acoustic characteristics optimization. Acoustic radiation intensity of the propeller under the condition of holding constant thrust may be reduced due to ratio optimization between the number of blades a propeller diameter and a circular speed value by minimum acoustic radiation power criterion. For substantial internal combustion engine noise reduction as a rule, intake and exhaust noise suppressors and silencers and different cowlings are used including those with vibration-proof and vibration-absorbing coating.

A role of different sources in total engine-propeller power plant noise depends on many factors. For essential engine-propeller PP aircraft community noise reduction it is necessary to affect, first of all, noise sources dominating in power plant running at a cruise flight mode-for UAV case and take-off operation mode-for light propeller aircraft as their communication noise approval is effected at that mode.

The present study generalizes the researcher's research results of engine-propeller PP acoustic characteristics and noise reduction methods including single different structure and arrangement propellers and petrol piston engines of external mixture generation (Moshkov and Samokhin, 2016a, 2017; Moshkov, 2014; Moshkov and Yakovlev, 2014) and also complements and generalizes those data with other researcher's investigation results (Hubbard, 1991; Hanson, 1980; Soderman and Horne, 1990; Block and Gentry, 1986; Society of Automotive Engineers, 1977).

ENGINE-PROPELLER POWER PLANT NOISE REDUCTION METHODS

Propeller noise reduction methods: Over the latest years the study on acoustic propeller optimization have been published, the basis of which is numerical noise generation process simulation (Zlenko *et al*., 2011; Gur and Rosen, 2009a, b; Pagano *et al*., 2008, 2009; Lefebvre *et al*., 2010). The results obtained refer to a limited field of structural propeller parameters and arrangement solution variation. Therefore, an important role in problem solution optimization is played by experimental investigation and semi-empirical noise generation process simulation. Certain calculation and experimental investigation results (Moshkov and

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Samokhin, 2016b, 2017) of major geometric aircraft propeller parameters and arrangement effect on acoustic characteristics are considered.

Number of blades and diameter effect: The number of blades increase with condition of geometric and aerodynamic propeller similarity conservation and also with constant circular speed mach number results in essential noise harmonic component intensity reduction from aerodynamic load. The other noise component intensities-thickness noise tone component and a propeller broadband noise component change negligibly at that. On the basis of semiempirical noise model (Samokhin, 2012) simple ratios have been proposed that allow to estimate a diameter and the number of blades effect on propeller noise tone components with condition of considered propeller thrust constancy and also with aerodynamic similarity conservation and circular speed mach number constancy (Moshkov and Samokhin, 2016a, b). Noise sound power calculation level change from aerodynamic load () is written in the following form:

$$\Delta L_{W_{\bar{p}}} = L_{w_{\bar{p}2}} - L_{w_{\bar{p}1}} = 20\lg\frac{d_1}{d_2} + 50\lg\frac{z_1}{z_2} \qquad (1)$$

For thickness noise () has the following form:

$$\Delta L_{W_{\overline{u_n}}} = L_{w_{\overline{u_n 2}}} - L_{w_{\overline{u_n 1}}} = 20\lg\frac{d_2}{d_1} + 10\lg\frac{z_2}{z_1} + 10\lg\frac{\left(M_{rot2}^2 + M_2^2\right)}{\left(M_{rot1}^2 + M_1^2\right)} \qquad (2)$$

Where:

d = Propeller diameter (m)

z = Number of blades

Mrot-tip = Rotational mach number

M = Flight mach number

It should be noted that the expressions presented are true only for propellers operating at Reynolds numbers Re >106. Acoustic characteristics measurements of two-and three-bladed propeller Yak-18T, MAI-223M and F30 performed at Moscow Institute air field in static conditions qualitatively proved a diameter and the number of blades effect on propeller noise calculation values.

Figure 1 gives a total measured sound power level (Lw) comparison of two-and-three-bladed propeller Yak-18T aircraft PP, accordingly with thrust being equal at 2, 4 and 2. The 5 m-diameter propellers and the same circular speeds. Since, the aircraft are powered by M-14 P one and the same engine, one can suppose that at similar operating mode a piston engine role will be the same for both power plants and therefore the data in Fig. 1 qualitatively characterize the number of blades and a diameter effect on propeller noise. One can see that under lower operation modes (M_{rot} ~0.5) the number of blade increase will result in essential power plant noise reduction by up to ~5 dB value. But as in operating mode rising there is a substantial thickness noise role increase in total propeller noise, a total noise reduction due to number of blades and diameter increase at M_{rot} >0.7 is ~2 dB.

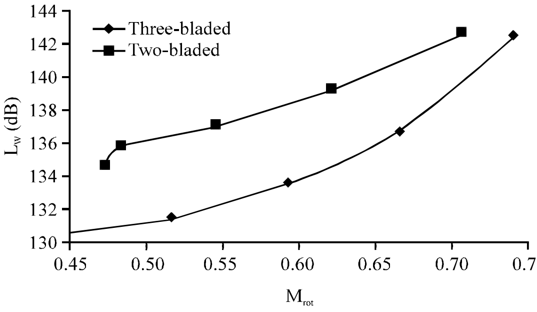

Fig. 1: Total measured sound power level comparison of two-and-three-bladed propeller Yak-18T aircraft PP depending on tip rotation speed mach number

For Yak-18T aircraft propeller the calculated aerodynamic load noise reduction with number of blades and diameter increase is ~9 dB which agrees with experimental data at lower operation modes. For expulsion noise a calculated growth due to the number of blades and diameter increase is ~2 dB.

In the same time the number of blades increase leads to harmonic component displacement in frequency radiation spectrum to a high-frequency domain and therefore in estimating noise and perceptibility in dB(A) an essential noise reduction effect may not be achieved. While investigating a diameter effect on MAI-223M and F30 propeller noise in static conditions it was stated that propeller diameter decrease by 3-5% (with negligible pitch increase to maintain constant take-off thrust) results in propeller noise reduction by ~1.5 dB (Moshkov and Samokhin, 2016a) in a wide operation range (Fig. 2). This negligible propeller diameter decrease with no blade plan shape change can be recommended as one of engine-propeller UAV PP noise and perceptibility reduction methods.

Blade plan shape effect: Another way of propeller noise reduction is blade tip shape change (Fig. 3). That shape change results in a certain displacement of radial aerodynamic load distribution maximum to the hub side, i.e., to displacement into the field of lower circular speeds. That kind of shape showed its efficiency for an aircraft propeller operation case at transonic and supersonic speeds and also while investigating helicopter rotors. On

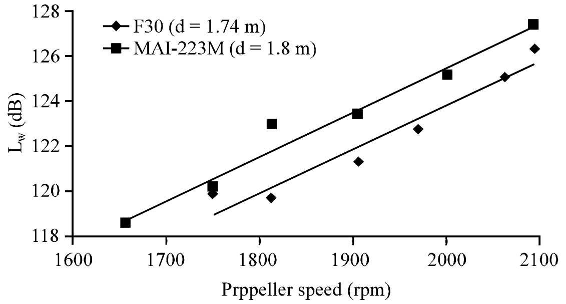

Fig. 2: Total propeller sound power level decrease with its diameter diminishing under condition of keeping constant thrust and rotation frequencies at different PP operation modes

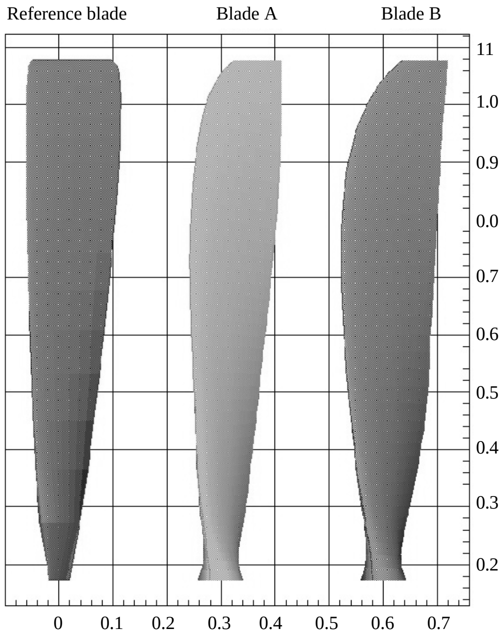

Fig. 3: Standard light aircraft and UAV propeller blade shapes

the whole one can note that propeller noise reduction abilities due to blade shape change are limited by foreign researchers up to 3 dB (Hubbard, 1991). It was stated that a blade shape change made a greater effect on aerodynamic rather than acoustic propeller characteristics. In experiment for blade A with modified leading edge tip a noise reduction level was received of up to 1.5 dB as against a reference one. Blade B would not give essential noise decrease not withstanding blade plan sweepback expressed sharply enough.

As a rule, under aeroacoustic blade shape optimization a purpose-oriented optimization function is propeller efficiency at the desired operation mode. For light aircraft that kind of mode is a maximum thrust mode, as aircraft community noise approval takes place at that mode. For UAV a typical mode will be that of a cruise flight. Control optimization parameters are blade setting and main non-dimensional geometric parameters, restrictions being thrust and noise level. Hereto an optimized propeller must be less noisy as against a base one.

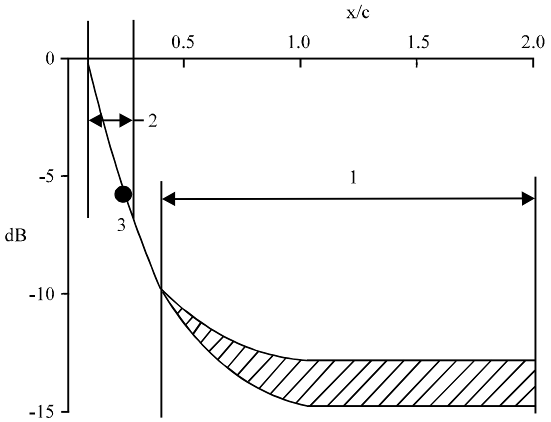

Fig. 4: Propeller noise harmonic component attenuation diagram with gap decrease between a propeller and a wing: 1: study data (Soderman and Horne, 1990); 2: study data (Block and Gentry, 1986), point 3 in the diagram researcher's investigation results (Moshkov and Samokhin, 2016a, b)

Acoustic features of pushing propellers: A propeller location in pushing arrangement results in wing (pylon or empennage) vortex wake entry onto a propeller. A non-uniform flow approaching a propeller leads to an unsteady load appearance at propeller blades and as a consequence, aerodynamic and acoustic change of pushing propeller characteristics in comparison with an isolated propeller case.

As a result of a flight experiment performed by Moshkov and Samokhin (2016a) an axial gap increase between a pushing propeller and a wing located ahead of it was stated to lead to propeller noise reduction at blade sequence harmonics. Flight experiment results have close agreement with foreign researcher's data (Soderman and Horne, 1990) received during aircraft model tests in the wind tunnel. One can see Fig. 4 that with relative axial gap increase up to x/c = 0.5 (x-distance between a propeller disc plane and wing trailing edge, c-wing mean aerodynamic chord) there is total tone noise radiation spectrum reduction up to 10 dB value. An axial gap increase above x/c >1 will result in airframe member vortex wake effect on propeller noise intensity becomes less by a value of up to 15 db and the difference between an isolated propeller noise levels and that one in a pushing arrangement becomes negligible. An axial gap increase may be considered as a structural way of decreasing light pusher aircraft community noise.

One can expect acoustic effect exhibition connected with a propeller as a pusher arrangement part to be reduced or even completely removed if to affect the ahead-located airframe member vortex wake. Sinnige *et al.* (2015) show that pylon air blowing can essentially produce an effect on a vortex wake intensity degree.

It was particularly set that similar influence on wing wake resulted in total propeller noise intensity decrease in the whole operation mode range considered. The greatest propeller noise intensity decrease on account of filling a turbulent wake (up to 7-12 dB) is seen under the most complete wake velocity profile leveling-off.

ICE noise reduction methods: A basic method of reducing piston engine structural noise not affecting an operation process is its cowling. Cowling application efficiency examination have been made by the researchers earlier and the results are presented by Moshkov and Yakovlev (2014). It was shown that cowling setting on silenced exhaust engine brought to main tone of the engine reduction in a total power plant noise ~18% through ~3% in a wide range of operation modes. With noise silencer absence in the engine exhaust system the engine cowling would not carry to total acoustic radiation intensity decrease as silencer-free gas exchange system noise intensity as a rule, exceeds structural noise intensity by more than 10 dB.

It should be also noted that engine cowling setting requires its vibration damping to avoid greater vibrations that may an additional noise source.

Among other methods of reducing ICE structural noise a power-speed coefficient increase should also be noted under the condition of a constant working volume, advance ignition angle and compression degree decrease as well as ribbed structural member vibration damping.

To diminish engine gas exchange system noise it is necessary to employ ICE intake and exhaust channel noise suppressors and silencers. If the engine has already an exhaust noise silencer installed, it is of concern to consider a large volume resonator silencer setting possibility as against a standard silencer. Resonator volume increase can bring to essential decrease of radiated noise levels in the field of low and mean frequencies. A vital and perspective factor is active noise silencing system set in the engine exhaust channels.

While selecting light aircraft and UAV PP it should be taken into account that two-stroke piston engines is a dominating source in engine-propeller PP noise with intake and exhaust channel noise suppressor and silencer absence.

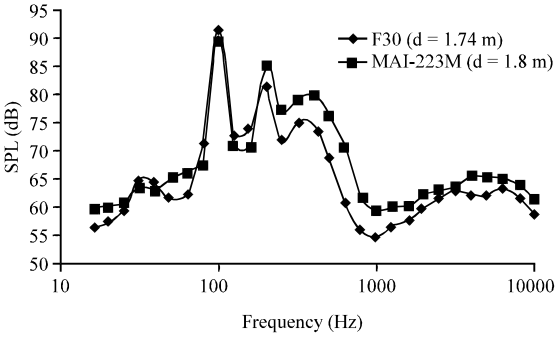

Fig. 5: Propeller diameter effect on three-octave sound pressure spectrum (= 120, propeller speed: 2094 rpm, static condition, distance: 30 m)

PROPELLER DIAMETER EFFECT ESTIMATION ON AIRCRAFT AUDIBILITY BOUNDARIES

As an example of aircraft community noise reduction on account of one of those methods considered in the present study propeller diameter effect estimation was made on small-size UAV acoustic detectability, the latter being powered by similar MAI-223M and F30 light aircraft power plant.

Figure 5 presents a comparison of measured three-octave sound pressure level spectra for MAI-223M and F30 power plants. One can see that total PP noise reduction by ~1.5 dB due to diameter decrease is caused by tone and broadband propeller noise component intensity decrease practically in the whole frequency range considered (Fig. 5).

On the basis of known algorithms and programs (Dmitriev and Samokhin, 2014) as well as experimental data one can estimate a propeller diameter effect on UAV audibility and detectability boundaries under conditions of standard or non-standard atmosphere (Arntzen *et al.*, 2014). For standard atmosphere conditions it was found that smaller diameter propeller A/C performing a cruise horizontal flight at low altitude and 140 km/hr speed can approach 300 m closer to a check terrain point, the observer failing to detect it.

CONCLUSION

Fundamental methods of reducing aircraft piston-engine power plants employed for light aircraft and unmanned air vehicles have been considered. The expressions are given that may be used to evaluate the number of blades and diameter effect on propeller noise tone component under the condition of aerodynamic similarity and constant tip speed Mach number. Pusher propeller features were described and noise reduction methods were proposed.

As one of the ways to reduce noise and perceptibility a piston-engine-powered UAV propeller diameter decrease version has been considered. The diameter decrease by 3.3% was found to bring to 300 m distance reduction that might be approached by UAV to a check terrain point without being detected.

Major perspective directions of future investigations are: shielding effect investigation of engine-propeller power plant noise by airframe members (Ostrikov and Denisov, 2016) and accounting this effect in determining UAV audibility and perceptibility boundaries. European researchers believe that due to shielding one can achieve propeller noise reduction in conditions of real arrangement up to a level lower than that of an isolated propeller (Delfs, 2016).

Shrouded propeller effect investigation on A/C community noise features (Oleson and Patrick, 1998; Abalakin *et al*., 2016). Parametric investigation of complex different-parameter effect upon acoustic characteristics of real engine-propeller PP on the basis of semi-empirical main source noise models (Samokhin, 2012; Moshkov, 2016) with purpose to reduce their noise under service conditions.

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