THE ESTIMATE OF HELICOPTER ROTOR NOISE FROM UNSTEADY FORCES

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ABSTRACT

The cost-efficient method to calculate the sound pressure due to main rotor unsteady forces in far acoustic field is proposed. As it is known, the evaluation of the sound pressure in relation to time allows estimating the main rotor acoustic characteristics. The paper aims at the enhancing the green safety of advanced helicopters and those being up-graded ones. The mathematical simulation of rotor noise emission is needed both to find out the phenomena physical essence (currently there is no unanimous opinion in re of noise emission processes of several types) and to predict analytically the rotors acoustic characteristics or the rotors combinations at different flight regimes. The unsteady load on the main rotor blade components is used in the proposed method that is based on Ffowcs Williams –Hawkings equation to calculate the sound pressure that is generated by main rotors [1, 2]. This load is estimated by calculation method based on non-linear theory of main rotor in non-stationary statement [3-5]. Such an approach is recognized as the most rational when constructing the methods of main rotor sound characteristics calculation because the rotation noise and the non-stationary noise constituents are taken into consideration including the load spikes conditioned by the interaction between the blade and the ahead blade tip vortex (BVI). Therefore the integrated analytic research is performed of rotation noise and vortex noise.

1. Introduction

The noise generated by helicopter is one of its most essential drawbacks. Moreover, the noise requirements are getting more toughening. Therefore the noise level estimation at design and update stages is a challenge.

Among the main helicopter noises it is to distinguish the impulse noise that is conditioned by the blade thickness, the main rotor rotation noise, the non-stationary forces noise on main rotor blades and as a consequence the noise generated by the interaction between the blade and the ahead blade tip vortex (BVI). Within this paper, the approach is proposed to calculate the sound pressure in the main rotor far acoustic field that is conditioned by non-stationary load on rotor blades and correspondently to calculate the main rotor acoustic characteristics.

2. Problem statement

Let the propagation of acoustic waves in frictionless fluid in infinite space be considered. The pressure and density are changed at that point where the sound wave is passing the medium, thus their current values are estimated in relation to the undisturbed p_o and ρ_o values and correspondently as:

$$p=p_o+p'; \ \rho=\rho_o+\rho'.$$

The p' value is also called a sound pressure. The sound waves propagation in the free space for the stationary medium or the uniformly moving one is described by the homogeneous wave equation that is obtained from the linearized equations of continuity and momentum conservation [1]

$$\frac{\partial^2 \rho}{\partial t^2} - c^2 \frac{\partial^2 \rho}{\partial x^2} = \Box_c^2 \rho = 0, \tag{1}$$

where: ρ – is density; c – is a sound velocity; x – is a spacial coordinate; $\Box_c^2$ – is a wave operator. The equation (1) in Lighthill theory[1] is modified by substituting into the right part the term that is equivalent to the distribution of compact acoustic quadrupoles, dipoles and sources correspondently:

$$\Box_c^2 \rho = \frac{\partial T_{ij}}{\partial x} - \frac{\partial P_1}{\partial x} + \frac{\partial Q}{\partial t}, \tag{2}$$

where: $T_{ij} = \rho U_i U_j$ – is a Lighthill stress tensor without regarding the viscosity for compact acoustic sources case.

When the Green free space function is chosen to solve the equation (2), it is possible to obtain the Ffowcs Williams–Hawkings equation[1], that describes the sound generation in body related system. The emission of quadrupole character may be neglected in the far field for which the distance to the observation point considerably surpasses the rotor diameter. Then this equation for acoustically rigid surface by neglecting its acceleration may be reduced to [1]:

(3)

$$4\pi p(t)=\rho\frac{\partial}{\partial t}\iint\left[\frac{V_n}{s(1-M_r)}\right]dS+\frac{1}{c}\frac{\partial}{\partial t}\iint\left[\frac{\Delta p\vec{n}(\vec{x}-\vec{y})}{s^2(1-M_r)}\right]dS,$$

where: V_n – normal velocity to surface; $\vec{x}$ – observation point radius vector; $\vec{y}$ – radiation point radius-vector; M_r – Mach number calculated for vector $(\vec{x}-\vec{y})$; $\vec{n}$ – normal to surface; $s^2=\left|\vec{x}-\vec{y}\right|^2$; dS – surface element.

The blade is to be considered infinitely thin, therefore Δp – is the delta pressure on the blade surface. Let the equation (3) be used to determine the sound pressure of rotor. Firstly we investigate the sound emission defined by dipoles, i. e. the second member of Equation (3).

The t time denotes the time required for the disturbance to achieve the observation point but as far as the time lag is different from the different blade points it is impossible to integrate by surface. The time differentiation is to be put under integral sign with taking into account that $t=t_e+s(t_e)/c$ and, $\partial t/\partial t_e=1-M_r$, where t_e – is a time of radiation from a concrete point at blade:

(4) $$4\pi p(t)=\frac{1}{c}\iint\left[\frac{\vec{n}(\vec{x}-\vec{y})}{s^2(1-M_r)}\frac{\partial}{\partial t}\frac{\Delta p}{(1-M_r)}\right]dS.$$

Let the codes be introduced (Figure 1): (x_0,y_0,z_0) – observation point coordinates, $\psi_r=\arcsin(z_0/x_o-M_x)$- observation point azimuth with consideration of time lag (at t_e moment of time); $\theta_r=\arcsin((y_o+M_z s_o)/s_o)$ – observation point longitude at t_e moment of time; M_x, M_z – Mach numbers estimated by velocity projections on X and Z axis; Ω – rotor circular RPM. Then the current blade point azimuth will defined by the relation:

$$\psi=\Omega t_e-\arcsin\frac{x}{r}-\psi_r,$$

where: x – is a blade point coordinate, counted off the leading edge; r – this point radius-vector taken to the rotor hub center.

The $(1-M_r)$ Doppler factor for far field may be recorded as follows:

(5) $$(1-M_r)=(1-M\cos\delta_r)(1+a\sin\psi),$$

where δ_r – is an angle between the vector towards the observer and the rotor hub velocity vector;

$$a=\frac{\Omega\sqrt{r^2+x^2}}{c(1-M\cos\delta_r)}\cos\theta_r.$$

In the formula (5), the first factor defines the time lag that is related with the rotor hub rotation and the second one defines the lag related with blades rotation in re to hub.

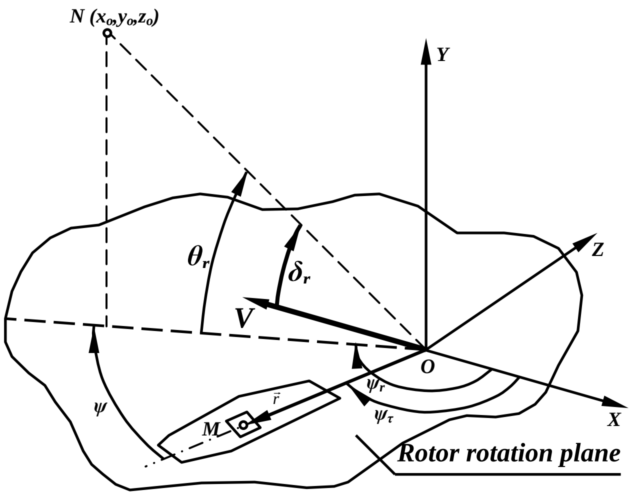

Figure 1. On the problem statement

As taking into account the mentioned above the expression (4) for the $p(t)$ acoustic pressure at t moment of time is reduced as follows:

$$p(t)=\frac{\Omega\sin\theta_r}{4\pi cs(1-M\cos\delta_r)^2}\times$$
$$\times\int_{r_0}^{R}\int_{x_l}^{x_t}\left[\frac{1}{(1+a\sin\psi)}\frac{\partial}{\partial\psi}\frac{\Delta p}{(1+a\sin\psi)}\right]dxdz.$$

Here the integration is made on the blade span from the tip of finned section of the blade r_0 till its end R as well as on the chord line from the leading edge till the trailing edge. Thus, to calculate $p(t)$ in any point of acoustic far field it is necessary to know the temporal distribution of aerodynamic load on blades.

3. BLADES AERODYNAMIC LOADS AND SOUND PRESSURE ESTIMATION

The methodology to calculate the main rotor blades unsteady aerodynamic loading is given in [3-5]. The movement kinetic parameters are assumed to be known. There are no restrictions imposed on neither rotor blade shape nor the type of their movement. The rotor blades are changed for infinitely thin basic surfaces. To define the loads on lifting surface areas the Cauchy-Lagrange integral is used. Under the numerical implementation of calculation method the continuous processes and distributions are substituted by time- and space discrete ones. Each rotor blade is divided into a certain number of panels along the radius and chord. In the center of these panels there are control points where the no-fluid-loss condition is implemented and the aerodynamic loads (Figure 2) are calculated. The blade azimuth position angle is taken as a non-dimensional time.

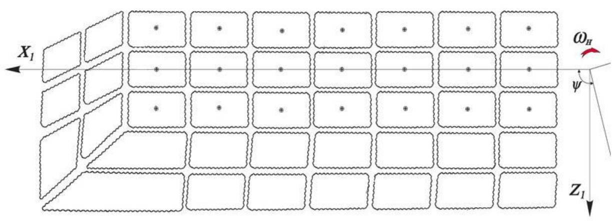

Figure 2. On the calculation method implementation

The blade-distributed aerodynamic loads obtained by the calculation method of nonlinear unsteady aerodynamic characteristics are substituted in Ffowcs Williams-Hawkings equation (3) to obtain the sound pressure as a time function.

$$p_i = \sum_{k}^{k_v} \frac{\Omega \sin\theta_r}{4\pi c S\left(1 - M\cos\delta_r\right)^2} \times$$
$$\times \sum_{l}^{L}\sum_{p}^{k_p}\left[\frac{(\partial D_{klp}/\partial\psi)_i}{(1+a\sin\psi)_{klp}}\right]F_{klp},$$

$$D_{klp} = \frac{\Delta p_{klp}}{(1+a\sin\psi)_{klp}},$$

where:

F_{klp} – blade panel area where the differential pressure acts,

k_v – is a number of rotors in combination,

L – is a number of blades of the k – th rotor,

k_p – is a number of blade panels of the k – th rotor.

The observation point coordinates are specified in the rotor related system. The main rotor kinetic parameters to be specified are: $V_н$, -velocity, $\alpha_н$, -angle of attack, $\omega_н$,- main rotor angular rotation rate, $\omega_н R$, -blade tip circular velocity, the time quantization parameters- – $\Delta\psi$ blade rotation angle per one design pitch.

Figure 3 presents as a pattern the results of simulating by the method proposed the 5-bladed main rotor flow around. The reference data are as follows: R=8.65 m is a rotor radius; $\omega_н R$=214 m/s is a blade tip circular velocity; $V_н$=60 m/s is a flow velocity.

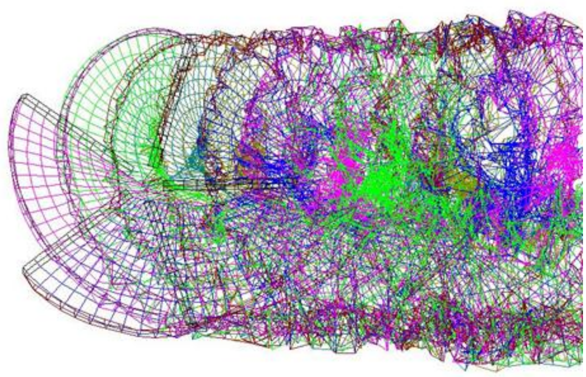

Figure 3. Simulation of the main rotor flow around

To check the validity of the proposed method the calculation results are compared with the flight test data (Figure 4). The flight test data are: helicopter weight 11 tons, D=17.25 m; ΩR=218 m/s; V=60 m/s, 5-bladed rotor. The observation point is situated at the distance of 150 m and its angle of elevation is θ=60°.

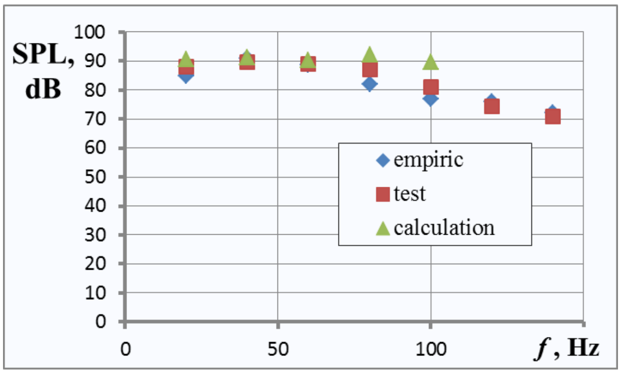

Figure 4 – Comparison to the flight test

E.g. Figure 5 and 6 show the results of determined sound pressure oscillation in observation points where the sound pressure is generated by the main rotor of the helicopter that has the in-flight weight of 10000 kg, the speed V=60 m/s (216 km/h).

The distance to the observation point was R_{obs}=150 m, the angle of elevation was θ=1°, 10° and 30°.

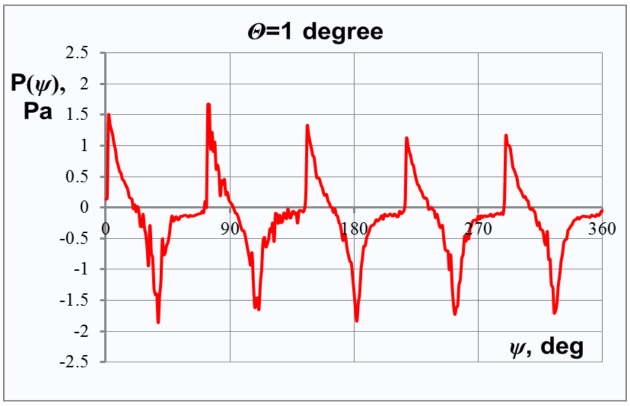

Figure 5 – Sound pressure oscillation, θ=1°

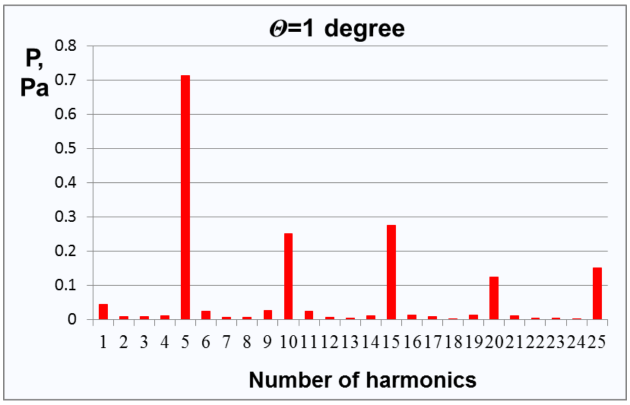

Figure 8 - Amplitude-frequency response, θ=1°

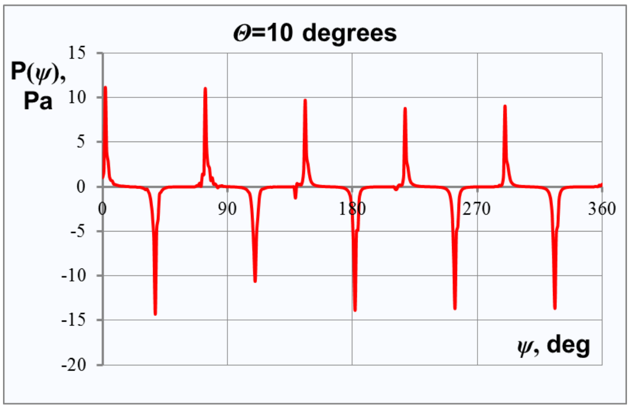

Figure 6 – Sound pressure oscillation, θ=10°

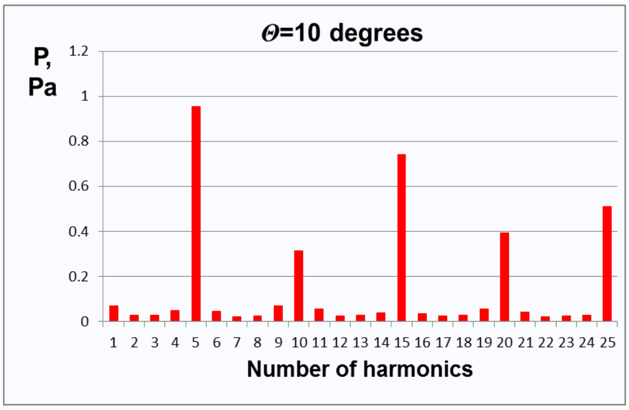

Figure 9 - Amplitude-frequency response, θ=10°

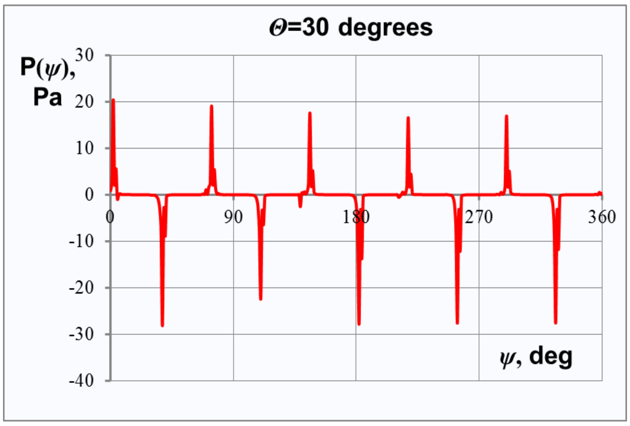

Figure 7 – Sound pressure oscillation, θ=30°

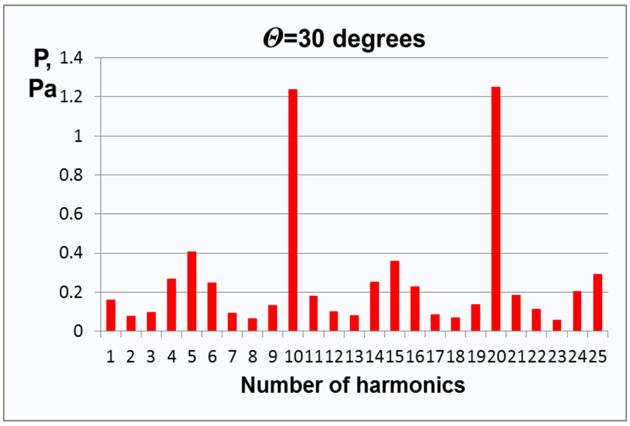

Figure 10 - Amplitude-frequency response, θ=30°

The overall sound pressure subject to harmonic analysis is defined. Figure 5, 6 and 7 show the sound pressure oscillation characteristics for the angle of elevations θ=1°, 10° and 30°. The influence of angle of elevation on the amplitude-frequency response is simulated (Figure 8, 9 and 10).

The diagrams of sound emission directivity are made for 5-bladed rigid main rotor (Figure 11 and 12) in vertical and horizontal planes.

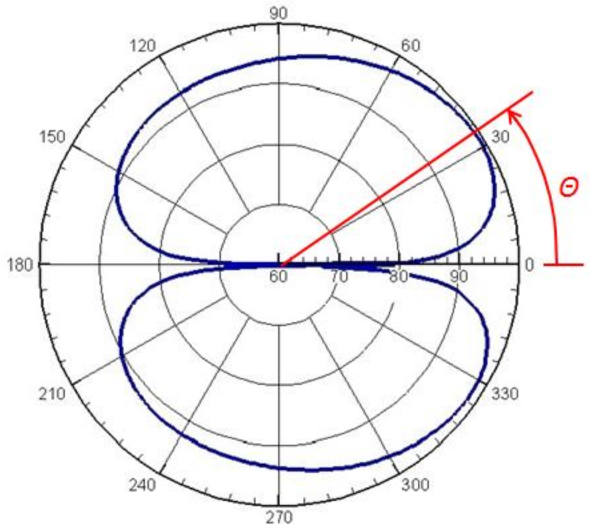

Figure 11 – Diagram of sound emission directivity in vertical plane, SPL (dB)

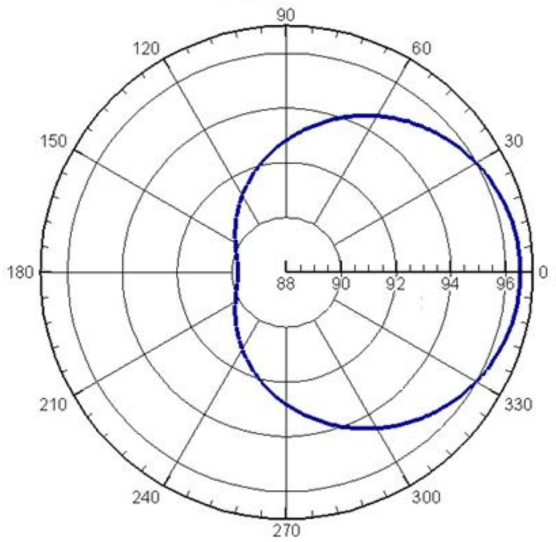

Figure 12 – Diagram of sound emission directivity in horizontal plane, SPL (dB)

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