# Modeling transient vibration-sound generation processes

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***Abstract*— In this paper, a problem of sound generation of two-blade rotor sinusoidal shape during helicopter landing is solved. Near and far sound field characteristics have been calculated. A comparative analysis of obtained numerical results with results for Mach number *0.2<M<0.4* is given. In particular noticed, that for a low Mach's number *M<0.1* transitional mode can occurs, which produces a blade flutter as a result.**

**Keywords — modeling transient processes, sound-vibration control, helicopter's noise.**

## I. INTRODUCTION

A number of studies have shown that the level of generated noise can be significantly reduced [1], [2], [3] using two approaches: 1) different bending of the blade along the span, 2) active damping of vibrations using the plates built into the blades. So in [1], active piezoceramic plates are used that are placed evenly along the surface of the blade with a certain interval at an angle $45^{\circ}$. This technology allowed us to reduce BVI noise (blade-vortex interaction noise) by 2-4 dB. In [2,3], microfibre polymers are used to reduce the vibrations that occur on the surface of the blade. However, experiments have shown that with a decrease in BVI noise by 2.5–2.7 dB, low-frequency oscillations and vibrations simultaneously increase. The work indicates that these two sources of noise are interconnected with each other, and it is not possible to completely get rid of them at the same time.

A review of active technologies available at that time for overcoming vibrations and BVI noise was presented in [4]. In particular, it is noted that the use of active piezoceramic components of the blade can significantly reduce vibration. In [5], the noise during helicopter landing was studied, the blades of which are equipped with active flexible plates. Studies have shown that with a simultaneous reduction in vibration, with a horizontal decrease of the helicopter (aircraft landing), a general increase in BVI noise of 1-3 dB is recorded on the ground. To overcome this problem, it is proposed to use the reverse control procedure [6]. It allows you to choose the optimal noise reduction of 4dB, while vibration is reduced by only 50%. That is, it was not possible to get rid of noise and vibrations at the same time. Piezoceramic actuators with a resonant frequency of 450 Hz are used in [7], which allow various vibration maneuvers of the helicopter (vertical rise, decrease) to achieve vibration reduction of 45% -90%.

Despite the fact that a number of studies during the first decades of this century have allowed some progress towards active control of the blade, reducing noise and vibration, the problem still remains unsolved. This is stated in [8], [9]: modern helicopters are still far from perfect in the issue of noise. The review presented in [9] motivates scientists to further search for ways to reduce the vibration and noise of the helicopter as a whole, a more detailed study of the transient processes of the transformation of sound into vibration.

In this report, the problem of generating a BVI noise by "sin-sin" blade "Blue-Edge" type for the landing mode (Fig.1) of a helicopter like an airplane is set and solved numerically for $M \le 1$. In this case, the sound generation model proposed earlier by the author [10], [11] was used. The characteristics of near and far sound fields were calculated using the numerical-analytical approach developed by the author. The Mach number range considered, *0.05 <M <0.1*, showed an increased noise level compared to *0.2 <M <0.4*. In particular, it has been observed that local areas of acoustic noise are transformed into vibration with energy being concentrated, which can lead to a flatter of the blade.

## II. PROBLEM SETTING, METHOD OF SOLVING

As a test blade, we take a double "sin-sin" bend blade. The cross section of the blade has a parabolic NASA-0012 profile. This blade showed the ability to significantly reduce BVI noise at moderate Mach numbers *0.2 <M <0.4* [12]. The physical model of the helicopter rotor load is as follows: vortices incident on the blade with insignificant Mach numbers are modeled as Taylor vortices both along and across

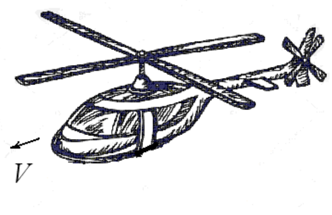


Figure. 1 Helicopter airplane landing

the blade (Fig.2). This model differs from the previously used model [10], [11] in that at small horizontal flight speeds the vortex flow around the rotor blade is formed more compactly.

The system of equations describing the ideal compressible flow around the blade [12] consists of the Euler equation and the continuity equation:

$$\rho \frac{d\bar{v}}{dt} = -\nabla p \ , \ \rho \frac{d\bar{v}}{dt} = -\nabla p \ . \qquad (1)$$

The boundary condition on the surface of the blade is the condition of non-penetrates:

$$\bar{v}_n = \bar{0} \ . \qquad (2)$$

In (1), (2) $\rho, p, \bar{v}$ – are flow density, pressure and velocity vector correspondingly.

Far from the blade, the flow is considered unperturbed with parameters $\rho_\infty, V_\infty$. Equations (1) - (2), taking into account the distribution of Taylor vortices, are an aerodynamic boundary-value problem. In numerical calculations, dimensionless variables were used. To simulate the acoustic problem, we use the system of equations [11], [12]:

$$\frac{\partial^2 \bar{\rho}'}{\partial \tau^2} - \frac{1}{M_\infty^2}\frac{\partial^2 \bar{\rho}'}{\partial \xi^2} - a^2(\lambda^2 c^2 \frac{\partial^2 \bar{\rho}'}{\partial \eta^2} + \frac{1}{AR^2}\frac{\partial^2 \bar{\rho}'}{\partial \zeta^2}) + \Re = Q \qquad (3)$$

$$\bar{\rho}(\frac{\partial^2 \bar{\phi}}{\partial \xi^2} - \lambda^2 c^2 \frac{\partial^2 \bar{\phi}}{\partial \xi^2} + \frac{1}{AR^2}\frac{\partial^2 \bar{\phi}}{\partial \zeta^2}) + c\frac{\partial \bar{\rho}}{\partial \xi}\frac{\partial \bar{\phi}}{\partial \xi} + \lambda^2 c^2 \frac{\partial \bar{\rho}}{\partial \eta}\frac{\partial \bar{\phi}}{\partial \eta} + \frac{1}{AR^2}\frac{\partial \bar{\rho}}{\partial \zeta}\frac{\partial \bar{\phi}}{\partial \zeta} =$$

$$= -[c\frac{\partial \bar{\rho}'}{\partial \tau} + \bar{\rho}'(c\frac{\partial \bar{u}}{\partial \xi} + \lambda c^2 \frac{\partial \bar{v}}{\partial \eta} + \frac{c^2}{R}\frac{\partial \bar{w}}{\partial \zeta}) + c\bar{u}\frac{\partial \bar{\rho}'}{\partial \xi} + \lambda c^2 \bar{v}\frac{\partial \bar{\rho}'}{\partial \eta} + \frac{c^2}{R}\bar{w}\frac{\partial \bar{\rho}'}{\partial \zeta}] \qquad (4)$$

Here $\Re$ and $Q$ is the convective and source terms corespondigly. In (3)-(4) $\bar{\rho}', \bar{\phi}'$ are acoustical density and sound potential correspondingly. The problem was solved in a rectangular Cartesian coordinate system using the numerical-analytical approach proposed earlier by the author [11].

## III. Near Field

The near-field calculation data was performed for a blade with double "sin-sin" bending for two values $\delta = 0.1; 0.2$ of the degree of bending. The angles of attack are $\gamma = 10^\circ; 5^\circ$, and the angle of the blade in the plane of rotation are $\alpha = 60^\circ, 90^\circ$. The relative degree of bending of the blade is the same for each of the two "sin"- bends of the blade. The dimensionless density $\rho'$ was chosen as the calculated characteristic of the near field.

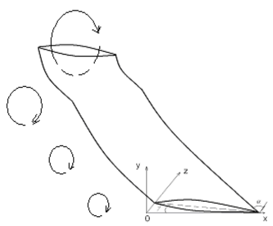

Figure. 2 Blade Flow Interaction

The calculation data for the Mach numbers $M \le 0.1$ showed interesting regularity. On the surfaces $\rho'$, distinct wave fronts in the front of the blade are observed only for $M = 0.1, \gamma = 10^\circ, \delta = 0.2$ (Fig. 3) at the angle of $\alpha = 90^\circ$ the blade to the flow. In the case $\alpha = 60^\circ$, these wave fronts disappear, and instead of them two distinct surge zones with a significantly increased amplitude of $\rho'$ appear. At the same time, for the values of the Mach numbers *0.2 <M <0.4* studied in [12], for both values of the angle of the blade to the flow, distinct sinusoidal wave fronts were observed. This can be explained as follows: the energy of the longitudinal oscillations of the waves (along the blade) is transformed into transverse vibrations localized in the form of two series.

And this situation is observed for almost all the calculated cases. For a blade with a smaller bend, $\alpha = 10^\circ, \delta = 0.1, M = 0.08 - 0.09$, sinusoidal wave fronts are only partially preserved, and perturbations that resemble perturbations in the case *0.2 <M <0.4* are observed behind them. In a number of design cases $\rho'$, zones appear where the amplitudes tend to go beyond the range of small perturbations, while there is a sharp concentration of sound energy in the form of peaks $\rho'$. And this is explained from the point of view of physics as follows: longitudinal wave fronts of BVI noise no longer dominate everywhere on the surface of the blade, and instead of them there are zones of sharp increase in amplitude $\rho'$. This is a transition process of degeneration, the transformation of sound vibrations into vibrations, accompanied by resonant phenomena. As the Mach numbers decrease on the surface of the blade, there are more and more areas of vibrational nature, the amplitude of which is 10-20 times higher than the maximum amplitudes of the BVI-noise.

In the case $\alpha = 10^\circ, \delta = 0.2$ (Fig. 4), local areas of bursts $\rho'$ are observed in a certain part of the blade: in the center of the blade and on its edge. Bursts of transverse disturbances are visible behind them. For a similar situation is also observed in the region of the trailing edge of the blade, where a second series of longitudinal wave fronts of relatively small amplitude is visible. Therefore, in this design case, the formation of both longitudinal and transverse fronts of perturbations occurs. This is precisely the transition process of the transformation of sound into vibration: there is no clear separation into vibration or sound generation. Against the general background of sound generation, nucleation of local vibration zones is observed with a sharp increase in amplitude.

At low Mach numbers, (Fig. 5), distinct resonance zones are observed: one or two peaks substantially dominate in amplitude over other disturbances observed on the surface of the blade. Four transverse wave fronts are already visible for the angle. Consequently, with a decrease in the speed of the

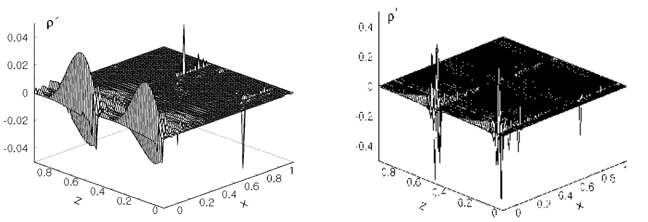

Figure.3 Dimensionless acoustical density: $M = 0.1, \alpha = 10^{\circ}, \delta = 0.2$,

a) $\gamma = 90^{\circ}$, b) $\gamma = 60^{\circ}$

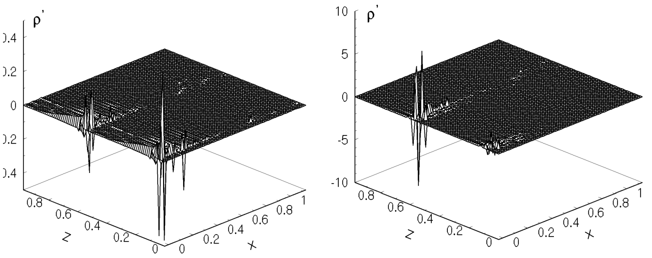

Figure.4 Dimensionless acoustical density: $M = 0.09, \alpha = 10^{\circ}, \delta = 0.2$,

a) $\gamma = 90^{\circ}$, b) $\gamma = 60^{\circ}$

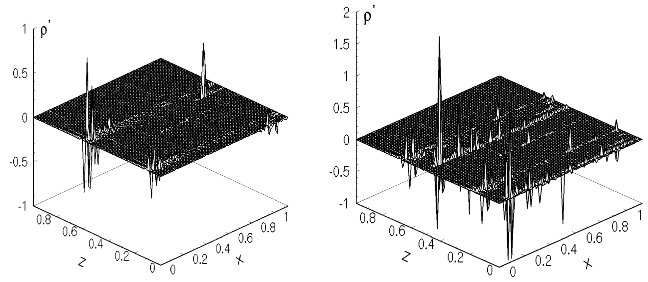

Figure.5 Dimensionless acoustical density: $M = 0.05, \alpha = 10^{\circ}, \delta = 0.2$,

a) $\gamma = 90^{\circ}$, b) $\gamma = 60^{\circ}$

incident flow, during an airplane landing of a helicopter, a partial transformation of the longitudinal wave fronts into transverse vibrations occurs with the appearance of distinct resonance zones.

## IV. Far Field

To study the far field, we used the integral representation given in [11]:

$$-M_1^2\int_S [\frac{F}{R}]_{t}^{*} dS_x - \int_S [\frac{1}{R}\frac{\partial\phi}{\partial n} + \frac{1}{Ra_\infty}\frac{\partial R}{\partial n}\frac{\partial\phi}{\partial t} - \phi\frac{\partial(1/R)}{\partial n}]_{t}^{*} dS = 4\pi\phi(x,t_1) \quad (5)$$

where

$$F = \rho[(\nabla\phi\cdot\nabla)\bar{v} + (\bar{v}\cdot\nabla)\cdot\nabla\phi] + \rho'(\bar{v}\cdot\nabla)\bar{v} + \bar{v}\cdot div(\rho\nabla\phi + \rho'\bar{v}) + \nabla\phi\, div(\rho\bar{v}).$$

Transient processes of transformation of the energy of longitudinal vibrations into transverse vibrations also affected the level of generated noise (Fig. 6-7). Frequently alternating oscillations of *L* (more often than in the case of *0.2 <M <0.4* [12]) tell us that the flow is characterized by significant instability. A characteristic feature here is the increased noise level of *L*, which was also observed in [10], [11]. This means that the resulting vibrations make the overall picture of the noise unfavorable. The calculation results showed that the overall noise level also becomes higher. The observer in this case hears instead of the usual noise an unpleasant, increased in level, annoying noise - a mixture of BVI noise and vibration [13], [14], [15]. And these vibrations can lead to flutter blades. Further research in this direction should be aimed at finding the optimal parameters of the blade in order to optimize the noise-vibration balance.

The frequency spectrum (Fig. 8-9) shows a significant activation not only of the first five harmonics, as was observed in [12], but of almost all frequencies in the spectrum. This suggests that the vortex component of the flow plays a major role. Not the rotation noise is now dominant, but the vortex noise - noise having the entire frequency spectrum. If in the case the level of harmonics gradually decreased with increasing frequency, then in the case the activation of harmonics is noticeable in the region of 650 Hz. In the case, we observe the widespread activation of a significant number of harmonics in the entire frequency domain.

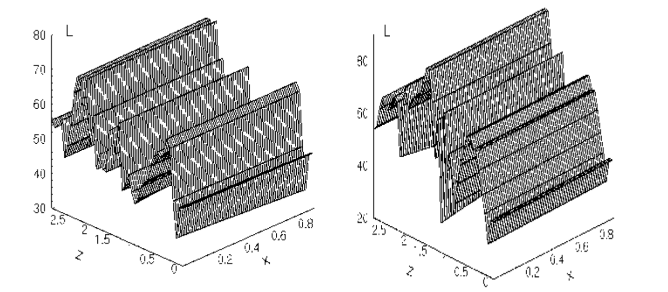

Figure. 6 Level of sound pressure: $M = 0.05, \gamma = 5^{\circ}, \delta = 0.1$,: a) $\alpha = 90^{\circ}$, b) $\alpha = 60^{\circ}$.

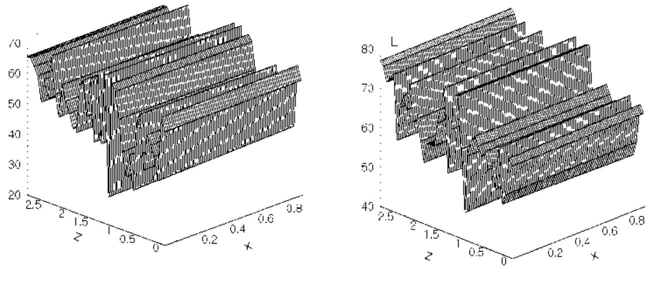

Figure. 7 Level of sound pressure: $M = 0.08, \gamma = 10^{\circ}, \delta = 0.2$,: a) $\alpha = 90^{\circ}$, b) $\alpha = 60^{\circ}$.

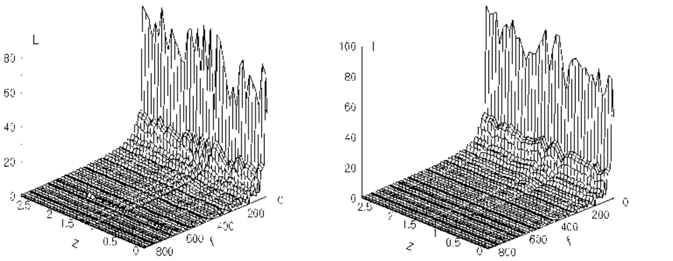

Figure. 8 Sound pressure spectrum: $M = 0.08, \gamma = 10^\circ, \delta = 0.2$ ,: a) $\alpha = 90^\circ$ , b) $\alpha = 60^\circ$ .

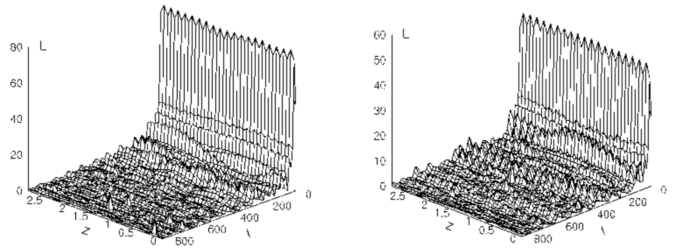

Figure. 9 Sound pressure spectrum: $\gamma = 5^\circ, \delta = 0.1$ ,: a) $\alpha = 10^\circ, \delta = 0.2$ , b) $M = 0.09, \alpha = 60^\circ$ .

## CONCLUSIONS

1. The problem of noise generation by a sin-sin blade in the airplane landing mode of a helicopter, at low Mach numbers, has been set and solved.

2. A numerical calculation showed the implementation of a transitional flow regime, that is, a flow in which BVI noise is present, and vibration areas. In this flow, in individual local regions of a partial transformation of the sound generation energy into the energy of vibrations occurs, which can cause flutter blades. An explanation of why active control is provided together with a reduction in vibration brings an additional increase in the level of BVI noise.

3. The calculation data showed that the total noise level generated in the airplane landing mode is higher than for the main mode straight flight. In this case, the activation of a large number of harmonics in the spectrum is noticeable for small angles of attack and degree bending of the blade, which was not observed for the straight helicopter flight mode.

4. Further research in this direction can be aimed at finding the optimal parameters of the blade in order to optimize balance noise - vibration.

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